NAVAL POSTGRADUATE SCHOOL

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THESIS

DISRUPTING COCAINE TRAFFICKING NETWORKS: INTERDICTING A COMBINED SOCIAL-FUNCTIONAL NETWORK MODEL

by

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March 2016

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The U.S. military has supported U.S. law enforcement in counter drug-trafficking efforts since the 1980s; the interagency counterdrug approach developed during that period—and still used today—focuses primarily on interdiction of cocaine conveyances in transit from South America to Central America. Increasing violence in the countries through which the cocaine transits is evidence that this approach is not working. Furthermore, the U.S. "rebalance" toward Asia and a worsening shortfall of interdiction assets signal a new strategic and operational environment that requires a counter threat network (CTN) approach.

Instead of simply attacking a functional trafficking network, as does an interdiction-focused strategy, we combine traditional Operations Research (OR) maximum flow and attacker-defender problems with social network analysis to directly interdict the traffickers' social-management network (and the resources it provides) in order to obtain indirect—yet potentially more effective—disruptions of the functional network. The Drug Trafficking Organization Social-Functional Network Interdiction (DTOSFNI) model described herein can be used to provide insight in order to combat the numerous trafficking organizations in a coherent manner—rather than relying upon independent, often isolated, investigations—and inform development of the Organized Crime Drug Enforcement Task Forces (OCDETF) Consolidated Priority Organization Target (CPOT) list and its associated investigations.

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DISRUPTING COCAINE TRAFFICKING NETWORKS: INTERDICTING A COMBINED SOCIAL-FUNCTIONAL NETWORK MODEL

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Instead of simply attacking a functional trafficking network, as does an interdiction-focused strategy, we combine traditional Operations Research (OR) maximum flow and attacker-defender problems with social network analysis to directly interdict the traffickers' social-management network (and the resources it provides) in order to obtain indirect—yet potentially more effective—disruptions of the functional network. The Drug Trafficking Organization Social-Functional Network Interdiction (DTOSFNI) model described herein can be used to provide insight in order to combat the numerous trafficking organizations in a coherent manner—rather than relying upon independent, often isolated, investigations—and inform development of the Organized Crime Drug Enforcement Task Forces (OCDETF) Consolidated Priority Organization Target (CPOT) list and its associated investigations.

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LIST OF ACRONYMS AND ABBREVIATIONS

AGI	Adversarial Goal Interdiction (Model)
AOI	area of interest
ASW	anti-submarine warfare
BPC	building partner capacity
C-IED	counter improvised explosive device
CARVER	criticality, accessibility, recuperability, vulnerability, effect, recognizability
CENTAM	Central America
COP	common operational picture
CPOT	Consolidated Priority Organization Target
CTN	counter threat network
CTOC	counter transnational organized crime
DEA	Drug Enforcement Agency
DOD	Department of Defense
D&M	detection and monitoring (operations)
DTO	drug trafficking organization
DTOSFNI	Drug Trafficking Organization Social-Functional Network Interdiction (model)
EPAC	Eastern Pacific (vector)
FBI	Federal Bureau of Investigation
FF	frigate
FFG	guided missile frigate
FNet	functional network
GAMS	General Algebraic Modeling System
GDP	gross domestic product
GFB	go-fast boat
I&A	interdiction and apprehension (operations)
IPC	Interagency Policy Committee
JDSD	Joint Doctrine Support Division
JIATF	joint interagency task force
JIATF-S	Joint Interagency Task Force South

JTF	joint task force
kg	kilogram
LCS	littoral combat ship
LES	Law Enforcement Sensitive
LSV	logistic support vessel
t	tonne or metric ton (1000 kg)
MCO	major combat operations
MLO	money laundering organization
MM	million
NDIC	National Drug Intelligence Center
NICCP	National Interdiction Command and Control Plan
NIDA	National Institute on Drug Abuse
NSC	National Security Council
OAS	Organization of American States
OCDETF	Organized Crime Drug Enforcement Task Forces
ONDCP	(United States) Office of National Drug Control Policy
PB	President's Budget
PL	Public Law
POM	Program Objective Memorandum
SNA	social network analysis
SNet	social network
SFNet	(combined) social-functional network
SPSS	self-propelled semi-submersible
SOTP	Special Operations Targeting Process
UNODC	United Nations Office on Drugs and Crime
USD	United States Dollar
USG	United States Government
USN	United States Navy
USCG	United States Coast Guard
USSOUTHCOM	United States Southern Command
WCARIB	Western Caribbean (vector)
WMD	weapon of mass destruction

EXECUTIVE SUMMARY

The U.S. military has supported U.S. law enforcement in counter drug-trafficking efforts since the 1980s; the interagency counterdrug approach developed during that period—and still used today—focuses primarily on interdiction of cocaine conveyances in transit from South America to Central America. Increasing violence in the countries through which the cocaine transits is evidence that this approach is not working. Furthermore, the U.S. "rebalance" toward Asia and a worsening shortfall of interdiction assets signal a new strategic and operational environment that requires a counter threat network (CTN) approach.

Due to this shortfall in interdiction assets and changing strategic environment, a new operational-strategic approach for countering drug trafficking from Latin America is warranted—one that seeks to disrupt not the vessels carrying the contraband, but instead the coordinators and financiers who resource the enterprise. Rather than a tactical question of how to best interdict trafficking conveyances, we seek to address questions of strategic and operational import by showing the benefit of interdicting the traffickers' social-management layer directly in order to achieve indirect effects on the physical flow of cocaine by removing the resources needed to conduct such movement. In doing so, we provide a potential roadmap for achieving three action items, and supporting a fourth, identified in the 2015 National Drug Control Strategy:

- (6.3.A) improve our knowledge of the vulnerabilities of transnational criminal organizations,
- (6.3.C) target transnational money laundering networks to deny drug trafficking organizations illicit financing and money laundering capabilities,
- (6.3.D) target cartel leadership and their networks, and
- (5.1.B) improve intelligence exchange and information sharing.

This thesis also provides an analytical approach to identifying which parts of the trafficking network may be good candidates for knowledge or intelligence development. Thus, improved prioritization schemes—based coherently on overall threat network

vulnerabilities vice independent individual- or DTO-based discriminators—may be used in the development of the Organized Crime Drug Enforcement Task Forces (OCDETF) Consolidated Priority Organization Target (CPOT) list and its associated investigations. While we use hypothetical, open-source data for our representative DTO network, specific Law Enforcement Sensitive (LES) data can be applied to the model in order to evaluate specific, real-world attack scenarios.

The trafficking of cocaine is a physical process involving a physical commodity. The constraints of geography and limited conveyance types allow us to define a functional network that is comprised of specific tasks that must be accomplished in order for cocaine to reach the U.S. homeland. For instance, cocaine can only be transported to Central America by air or by sea. Likewise, cocaine smuggling across the southwest U.S.-Mexico border can only be accomplished via air, surface, or sub-surface means. This functional workflow process forms the backbone of our model. Unlike traditional maritime and other interdiction strategies (such as the one currently employed by DOD and U.S. law enforcement), however, we do not directly interdict this functional network.

Cocaine does not move by itself. There are people and organizations that seek to profit from its movement and sale, and these drug trafficking organizations, or DTOs, expend resources in order to maximize that profit, whether through the arbitrage of the cocaine's value as it nears the U.S. or from its direct sale. Using hypothetical data based on open-source material, we define a social network of three main categories of archetypical DTOs (with associated DTO-specific identifier code): those operating in the source zone (A and B), intermediate-level transport organizations in Central America and Mexico (C, D, F, and I), and core Mexican cartel-level organizations (E, G, and H). Each of these organizations has a particular role in the trafficking enterprise and an associated mindset or agenda, which helps define their steady-state resources immediately available. We assume that these DTOs cooperate to varying degrees as a single enterprise, and that all decisions made by each DTO will be for the benefit of the whole.

By combining the social network and the functional network into a single social-functional network, we can observe how certain organizations with a given set of resources act in order to move the maximum amount of cocaine each month to the U.S.

homeland. We then use an attacker-defender optimization as the basis of our analysis. While the defender (e.g., traffickers) attempts to maximize accrued rewards, the attacker (e.g., U.S. law enforcement and military) attempts to minimize this outcome. Known as a min-max Stackelberg game, the attacker moves first to interdict one or more social nodes, followed by the defender's response to that attack (maximize cocaine flow along the surviving paths and/or shift resources between social entities to enable such flow).

Our Drug Trafficking Organization Social-Functional Network Interdiction (DTOSFNI) model is a linear program representation of the conceptual social-functional network. The trafficking enterprise seeks the optimum distribution of resources to maximize *steady-state* monthly financial profit in the equivalent of millions of U.S. dollars (USD). It allows the enterprise to decide what types of resources to apply to which functional tasks, and whether or not to shift resources between DTOs. The model rewards the traffickers for moving an amount of cocaine to each successive level in the network, reflecting the increasing value of cocaine as it nears the U.S. market. The model also imposes costs to employ a given type of resource for a given task, as well as penalties for shifting resources between social entities and for attempting to move resources through, or apply resources from, an interdicted social node.

We enumerate the possible attack plans and determine results for an un-interdicted base case, and when one, two, or three DTOs are attacked. This allows us to better determine priorities for investigation and attack among the various DTOs and allows us to quickly see alternatives if a particular attack plan is not available to us in the real world. We can also use secondary information provided by the DTOSFNI model to evaluate evidence-gathering prospects or to observe potential responses by remaining DTOs under a given attack plan. This also provides insight on how best to sequence attacks against particular DTOs.

The base case moves all 53.0 metric tons (based on hypothetical data to maintain appropriate classification levels) of cocaine produced each month by the Colombian sources to the U.S. homeland, netting the traffickers $5.3 billion in monthly profit (note these are hypothetical numbers for this instance of the problem). We find that, overall, A and E are the most lucrative targets, followed closely by B and F. Combinations of these

organizations tend to yield greater profit reductions, while combinations of the other DTOs tend to be inconsequential. Some multi-attack combinations provide no additional reductions or perform worse than plans with fewer attacks.

When only one attack is available, the top three attack plans—A, B, and E—all focus on DTOs that provide significant contributions to the task of moving cocaine from Colombia to Central America primarily by maritime means. Reductions in profit (or flow) for these three attack options range between 12.6–21.2%.

When two attacks are available, three of the top five performing attack plans include DTO-A, and four of the top five incorporate either or both of the source zone DTOs. The dual AB attack yields the best results as it essentially cuts off Colombia from the rest of the supply chain. We also see that a single attack on DTO-E dominates any other dual attack against two Mexican cartel-level DTOs, with the exception of the GH combination. Reductions in profit for the top five dual attack options range between 34.1–91.0%.

The triple attack options yield some interesting results. The dual AB attack again dominates every triple attack plan, and the 2nd-best dual AE attack dominates all but two triple attack plans, with the exceptions being EFG (74.4% profit reduction) and AEF (63.5%). As with the dual attack results, a triple attack plan focused on the Mexican cartel-level DTOs (the EGH attack) is dominated by at least seven other multiple-attack plans.

While no one needs a model to see that isolating a geographically-constrained cocaine-producing region from the rest of the supply chain yields the greatest profit and flow reductions, the DTOSFNI model is useful in addressing, "What else?" if such an attack plan is not feasible. The quantitative model also allows us to truly analyze what would be impossible to do so manually or qualitatively.

Just the *process* of obtaining and inputting data into the DTOSFNI model also provides significant value to decision-makers. First, the process requires the explicit identification of assumptions. Next, archiving these assumptions in a common format should allow different parties in the "blue" network (such as the Federal Bureau of

Investigation, Drug Enforcement Agency, U.S. military and other intelligence agencies, etc.) the ability to share such knowledge and challenge disparate estimates more transparently. Finally, increased sharing of such structured information (policy restrictions notwithstanding) allows for the development of a true counterdrug Common Operational Picture (COP). One such manifestation of this COP could be a living diagram of the social and functional networks as described in this thesis.

Potential applications of the DTOSFNI and its process, therefore, include not just “simple” targeting prioritizations, but also identifying knowledge gaps and policy obstacles to information sharing across the counterdrug community. Empowerment of information-sharing fora, beyond what has already been—and continues to be—done at JIATF-S as an example, and using a comprehensive approach may provide the counterdrug community with a means for increased success against cocaine trafficking.

The OCDETF CPOT list is another coordinating mechanism. Though it is unclear whether a comprehensive prioritization of investigative effort occurs, the DTOSFNI model can be extremely useful in supporting such an approach. Removing all the major Mexican cartels is not the answer, even if it were feasible. However, removing the right combinations of DTOs can achieve significantly greater reductions in profit, and the DTOSFNI model can help identify which combinations to pursue.

The DTOSFNI model can also be used to anticipate DTO responses to attack, at least in terms of social resource transfers and direct applications to the functional network. While we focus on how attacks change the level of overt activity of a particular behind-the-scenes DTO, this same approach can be used to evaluate how any DTO may react to a network attack and law enforcement can set up evidence-gathering efforts accordingly. Evidence-gathering and actual interdiction activity can and should inform each other: they are not mutually exclusive goals.

In conclusion, we have demonstrated the value of combining traditional operations research and social analysis techniques into a hybrid model that considers both the social actors themselves and the goals they are attempting to achieve, in order to evaluate interdiction options to disrupt achievement of those goals. The drug trafficking

problem is certainly a very complex and extensive one and there is no guarantee of obtaining optimum attack results by simply “eyeballing” the problem using experience and instinct. The results clearly indicate that DTOs are not alike and cannot be targeted haphazardly. However, we have shown that a comprehensive, methodical, and analytical approach, such the one used to develop the DTOSFNI model, can help elicit otherwise unforeseen insights and be useful for informing the development of counterdrug strategy and/or policy.

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Damn the torpedoes, full speed ahead!

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I. INTRODUCTION

The global cocaine market is estimated to be an $85 billion per year enterprise, while the size of the U.S. cocaine market is estimated to be about $38 billion annually (OAS 2013). Not only is there a significant economic incentive for cocaine traffickers to continue operating, there is also an outsized economic detriment to the United States society. The overall economic cost to society of illicit drug use was estimated to be $193 billion in 2007; assuming cocaine accounts for roughly one-third of this number, the socio-economic cost of cocaine use alone exceeds $64 billion annually (NDIC 2011). Then there is the human cost of cocaine trafficking; according to the National Institute on Drug Abuse, deaths in the United States from cocaine overdose in 2013 numbered approximately 5,000, a 29% increase from 2001 (NIDA 2015).

The Department of Defense (DOD) has been involved in counterdrug operations since 1989, but in many ways the security situation in Mexico and Central America has only gotten worse in that time. Recent changes to national priorities and budgetary pressures make the DOD Countering Transnational Organized Crime (CTOC) mission even more difficult to execute. Tactical interdiction-centric operational approaches have improved over the years due to previous studies and research, but these approaches rely upon one critical assumption: the continued availability and employment of military-provided maritime interdiction assets. The recent retirement of the U.S. Navy's *Oliver Hazard Perry*-class guided missile frigates (FFGs) in September 2015 calls into question this central assumption. While the Littoral Combat Ship (LCS) was redesigned and re-designated as a frigate (FF), this platform has not yet been fielded in significant numbers and the U.S. Navy's strategic shift to the Pacific theater suggests that these ships will not be prioritized for future counterdrug missions.

Due to this shortfall in interdiction assets, this thesis suggests that a different operational-strategic approach for countering drug trafficking from Latin America is warranted—one that seeks to disrupt not the vessels carrying the contraband, but instead the coordinators and financiers who resource the enterprise. We illustrate that the

interdiction of the people or organizations that supply these resources may disrupt trafficking indirectly, and on an even greater scale.

A. COCAINE AND ILLICIT TRAFFICKING: A DESTABILIZING THREAT

Drug trafficking organizations (DTOs), criminal entities that exist primarily to make money from the trafficking of illegal narcotics, and networks operating between South and North America increasingly threaten the security of the United States and that of its partners in Central America and Mexico. While these DTOs create revenue through a myriad of illicit activities—from drug production and smuggling, to human- and weapons-trafficking—cocaine trafficking remains the primary driver for the DTOs' existence. The unique origins of cocaine, the continued demand in the United States, the geo-physical considerations of transporting the contraband, and the existence of already weak Central American government institutions combine to create trafficking corridors that extend from the Andean region of South America to the U.S. Southwest Border. Numerous competing and collaborating DTOs operate along these corridors with relative impunity.

Cocaine is a drug derived from the coca plant, which grows only in the mountainous Andean region of South America. While estimates vary, production-based methods used by the Office of National Drug Control Policy (ONDCP) indicate that about 633 metric tons (t) of cocaine are produced annually. Of this estimated amount, roughly 55–59% is smuggled into the United States, with nearly this entire portion being sourced in Colombia (ONDCP 2012).

As indicated in Figure 1, approximately 91% of the cocaine flow into the U.S. transits what is known as the Mexico-Central American Corridor, with the rest moving through the Caribbean Corridor (ONDCP 2012). The Darién Gap—a large break in the Pan-American Highway in the swampy and largely impassable region between Colombia and Panama—is a natural barrier to transit and, hence, ground-based drug trafficking. This gap forces any northward flow of cocaine along the Mexican-Central American Corridor to use airborne or seaborne transit modes along two distinct vectors: an Eastern Pacific (EPAC) vector (53% of total flow) and a Western Caribbean (WCARIB) vector

(38% of total flow). Nearly all of the flow through this corridor transits one or more countries in Central America, as well as Mexico, on its way to the United States (ONDCP 2012).

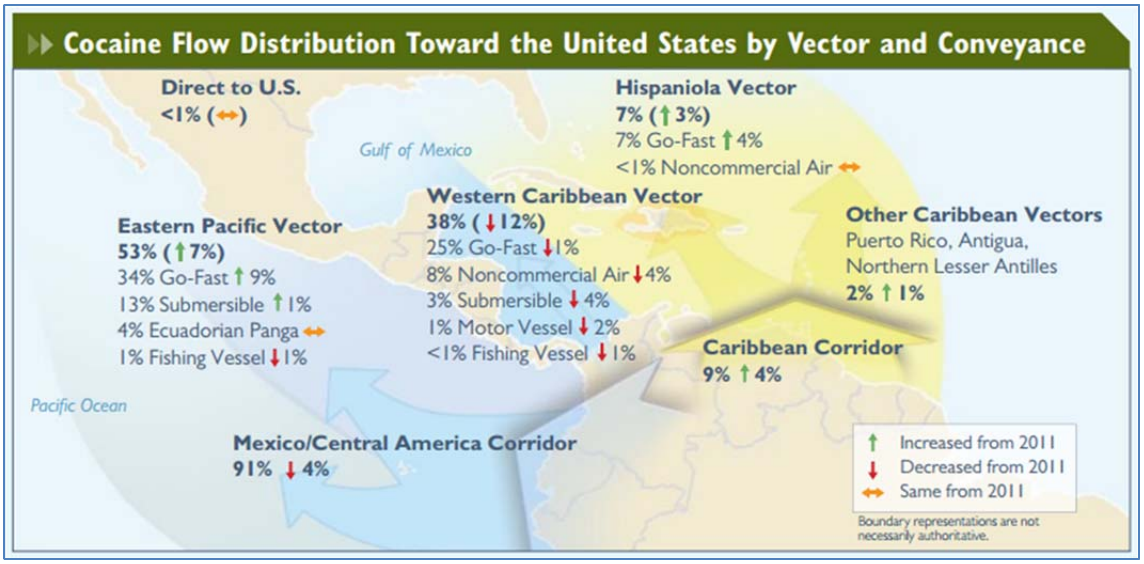

Figure 1. Map of Cocaine Trafficking Corridors and Vectors

Adapted from: Office of National Drug Control Policy (2012) Cocaine Smuggling in 2012. Report, United States Office of National Drug Control Policy, Washington, DC. The 2011 ONDCP estimates for the distribution of cocaine trafficking conveyances on the way to the United States is shown in this graphic. It is unclear whether this distribution refers to total tonnage by conveyance or to the number of trafficking events by conveyance. The primary conveyance used is the go-fast boat (accounting for over 70% of cocaine flow), followed by the self-propelled semi-submersible. Aircraft account for a smaller percentage of conveyances used, and primarily operate in the Western Caribbean vector. This thesis focuses on the 91% of cocaine that flows to the U.S. via the Eastern Pacific and Western Caribbean vectors in the Mexico/Central America Corridor.

There are three primary conveyance types used to transport cocaine from South America into Central America: surface maritime vessels, maritime submersibles, and aircraft. While some cocaine is trafficked via fishing vessels (such as an Ecuadorian *panga*) or other commercial motor vessels, for the purposes of this thesis all surface maritime conveyances are considered to be a *go-fast boat* (GFB)—a fast, lightweight speedboat made of fiberglass to minimize radar signature, which accounts for a vast majority of the conveyances used (Figure 2).

Figure 2. Go-Fast Boat

A suspected drug-trafficking go-fast boat is chased down by Bahamian police. Photo courtesy of U.S. Coast Guard.

A *self-propelled semi-submersible* (SPSS) is a purpose-built submarine constructed from fiberglass and with a low freeboard (Figure 3). Early SPSS designs were smaller and could only carry about five metric tons (t, or tonnes) of cocaine, but these vessels have grown larger over the years, with some capacities approaching 12t (Davis 2013).

Figure 3. Self-Propelled Semi-Submersible

U.S. Coast Guard personnel inspect a captured SPSS carrying roughly 7.3t of cocaine. Photo courtesy of U.S. Coast Guard.

For the purposes of this thesis, there are three main types of representative aircraft used: twin-engine aircraft (such as the Cessna 402) for long-range transport from South America to Central America and then onward into Mexico; single-engine aircraft (such as

the Cessna 172) for short-range transport; and ultralight aircraft for cross-border transport from Mexico into the USA (Figure 4).

Figure 4. Representative Drug-Trafficking Aircraft

Clockwise from Left: Cessna 402, Cessna 172, and an ultralight. Photos courtesy of Wikipedia.org.

This model also uses ground-based resources (to include commercial trucks and private automobiles) to transport cocaine. Table 1 summarizes rough capacities for the various types of conveyances described herein.

Table 1. Estimated Capacities for Trafficking Conveyances

Conveyance Type	**Estimated Capacity (t)**
GFB	0.5–2.0
SPSS	5.0–12.0
Twin-engine Aircraft	0.4–1.4
Single-Engine Aircraft	0.2–0.3
Ultralight Aircraft	0.1
Commercial Truck	0.05–0.9
Automobile	0.03

Capacity per unit resource varies dependent upon where the resource is applied and in what quantity. This is described in further detail as a capacity function in Chapter III.

The effect of the trafficking of cocaine and other illicit drugs through Central America and Mexico cannot be denied, and the illicit trafficking networks that permeate

this corridor are an increasingly destabilizing regional security threat. As shown in Figure 5, despite the counter-narcotics activities of the U.S. government (USG) interagency—to include the Drug Enforcement Agency (DEA), Federal Bureau of Investigation (FBI), U.S. Coast Guard (USCG), U.S. Navy (USN), and Joint Interagency Task Force South (JIATF-S) among others—the homicide rates in Honduras, Mexico, and Belize have increased rapidly since 2006. Furthermore, illicit trafficking is such a lucrative enterprise that DTOs, as a whole, generate more revenue than many Central American countries spend on their entire security sectors. In some cases, the value of the drugs being moved annually through a given Central American country can exceed 14% of that country's GDP (UNODC 2012).

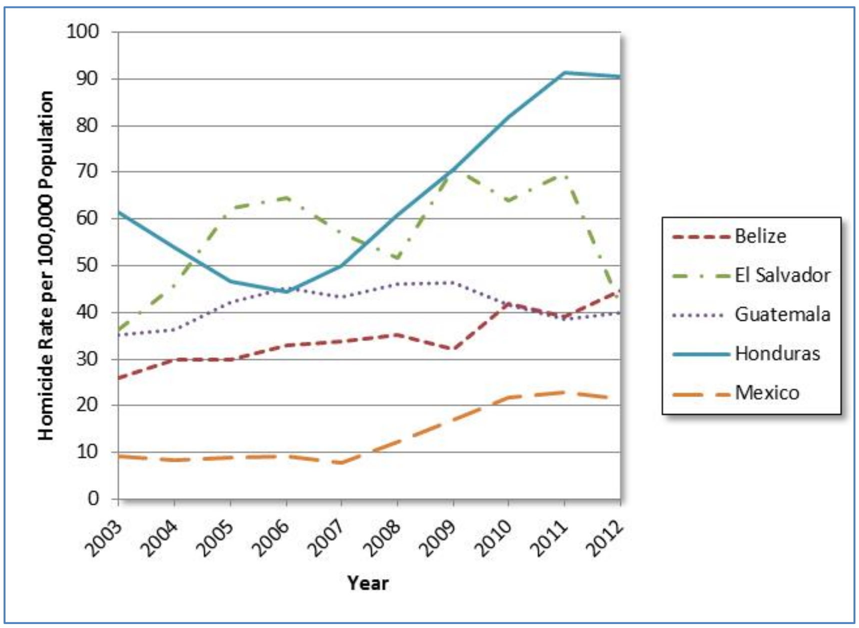

Figure 5. Homicide Rates for the Northern Triangle, Belize, and Mexico (2003–2012)

Adapted from: United Nations Office on Drugs and Crime (2013) Global Study on Homicide 2013. Report, United Nations Office on Drugs and Crime, Vienna. In 2012, the homicide rates per 100,000 persons in the Northern Triangle countries—Guatemala (39.9), Honduras (90.4), and El Salvador (41.2)—far exceeded the rates of Mexico (21.7) and the U.S. (4.7, not shown). Mexico, Belize, and especially Honduras have seen a significant increase in homicide rate since 2006 despite ongoing counterdrug efforts.

The violence and disruption is not limited to areas far removed from the U.S. homeland. In 2014, the massacre of 43 college students in Mexico was linked to drug traffickers and corrupt officials. In July 2015, Joaquín Guzmán-Loera aka *El Chapo*, head of the preeminent Sinaloa Cartel, escaped from a Mexican prison after being in custody barely over a year. Furthermore, in his 2014 Posture Statement to Congress, General John F. Kelly, commander of United States Southern Command (USSOUTHCOM), testified, "Driven by economic pressures and rising criminal violence, the number of Hondurans, Guatemalans, and Salvadorans attempting to cross the U.S. Southwest border increased 60% in 2013" (Kelly 2014). According to a memorandum summarizing the conclusions from an Interagency Policy Committee (IPC) meeting on Central America, "U.S. security is intimately linked to the security and prosperity of Central America" (NSC 2014). Furthermore, the 2015 National Security Strategy identifies transnational organized crime associated with weak or failing states as a top strategic risk to U.S. national interest (Obama 2015a).

B. JOINT INTERAGENCY TASK FORCE SOUTH: A HISTORY

The threat to the U.S. from cocaine and drug trafficking is not new; U.S. government efforts to counter such activities date to the early 1980s and the rise of powerful Colombian drug cartels. The failure of traditional civilian law enforcement to effectively counter this rising threat led the Reagan Administration and Congress to conclude that greater centralized authority—via a dedicated, standing national task force supported by the military—was needed (Munsing and Lamb 2011).

Beginning with the *Department of Defense Authorization Act of 1982* (PL 97-86), Congress amended the *Posse Comitatus Act*—which limited the ability of the federal government to use military personnel for domestic law enforcement—to allow the Secretary of Defense to support federal, state, and local civilian law enforcement agencies with the "use of military equipment and facilities," as well as "the use of information" (e.g., intelligence and surveillance); prohibitions against use of DOD personnel to directly conduct searches, seizures, and make arrests remained in place. Essentially, this amendment allowed U.S. Navy vessels to track, follow, and stop a

suspected drug smuggling vessel, while embarked law enforcement or USCG personnel would conduct the actual boarding, searches, and arrests.

Subsequently, several presidential directives and congressional actions further modified the U.S. government's counterdrug approach. President Reagan's National Security Decision Directive 221 "declared narco-trafficking a national security threat and authorized the Secretary of Defense" to expand DOD counternarcotics involvement in 1986 (Munsing and Lamb 2011). The *Anti-Drug Abuse Act of 1988* (PL100–690) established the ONDCP in the Executive Office of the President to facilitate "coordination between executive branch departments and agencies" and to certify that their drug control budget submissions were "consistent with the National Drug Control Strategy [and/or] Program." The Act also authorized the President to "designate lead agencies with areas of responsibility for carrying out the National Drug Control Strategy." As such, and in keeping with intent of the *Posse Comitatus Act* modifications, *The National Defense Authorization Act for Fiscal Year 1989* (PL 100-456) "designated DOD as the lead agency for detection and monitoring [(D&M)] of drug trafficking into the United States, and the [US] Coast Guard as the lead agency for interdiction and arrest [(I&A)]" of the drug traffickers themselves (Munsing and Lamb 2011).

This approach centered almost exclusively upon the interdiction of drug trafficking routes. The DOD established several regionally aligned *joint task forces* (JTFs), organizations comprised primarily of military members from two or more *military* departments (Navy, Air Force, or Army) operating under a single joint force commander and assigned a narrow task or set of tasks. A JTF may also have civilian members employed by a given military department. Joint Task Force-4 (JTF-4) in Key West, Florida, was one of several new regionally-aligned counter-drug JTFs, and was responsible for D&M in the Caribbean (Munsing and Lamb 2011). The military-centric JTF-4 construct was a step forward in interagency cooperation in the war on drugs, but had no dedicated assets and had no way to compel cooperation from the various force and asset providers (Munsing and Lamb 2011).

In 1993, President Clinton signed Presidential Decision Directive 14 (PDD-14), which shifted the American counterdrug focus closer to the source countries. This signified a strategic shift away from solely stopping narcotics shipment "to a more evenly distributed effort across three programs:

> - Assisting Institutions in… nations… that demonstrate the political will to fight the narcotics syndicates…. [and] strengthen the political will to combat trafficking in key countries where that commitment is weak….
>
> - Destroying Narco-Trafficking Organizations… in a coordinated program to arrest… the narcotics syndicate leadership…. defeat narcotics money laundering…. [and] control the precursor chemicals essential for drug production….
>
> - Interdiction… at and near the border, in the transit zone [between South America and the United States], and in source countries." (Clinton 1993a)

Additionally, Clinton's Executive Order 12880 consolidated more authority for the war on drugs in the ONDCP (Clinton 1993b). In order to overcome the shortfalls of the JTF structure, ONDCP issued the first National Interdiction Command and Control Plan (NICCP) on April 17, 1994, which introduced the concept of the *Joint Interagency Task Force* (JIATF), an organizational structure "'manned and led by personnel from the various agencies with a drug interdiction mission,'" including civilian organizations such as the Drug Enforcement Agency (DEA) and the Federal Bureau of Investigation (FBI) (Munsing and Lamb 2011). Furthermore, as a "national task force" the JIATF command structure was such that physical assets of these agencies could now be put under its direct tactical control (Munsing and Lamb 2011).

The former JTF-4 became JIATF-East, and JTF-South, an existing task force with only cursory involvement in the drug war, became JIATF-South (Munsing and Lamb 2011). Later, these two organizations combined to comprise the current JIATF-South (JIATF-S) organization, which nests militarily under USSOUTHCOM. Today the command has three primary mission areas—encompassed in Operation MARTILLO (Hammer)—through which it supports U.S. and partner nation security: D&M operational support to multiple international and interagency stakeholders; information-

intelligence fusion; and facilitation and/or support to I&A operations conducted by interagency or international interdiction forces.

C. A SHIFTING OPERATIONAL-STRATEGIC CONTEXT

Despite the comprehensive approach prescribed by PDD-14, Operation MARTILLO follows a traditional operational approach—born in the 1980s—that is heavily oriented toward *tactical* maritime D&M and support to I&A (primarily U.S. law enforcement entities) of drug trafficking vessels on the high seas. This focuses more on the actual drug conveyances and/or crew of the vessels used in the drug trafficking enterprise than upon the higher-level coordinators or financiers of the enterprise (though there are nascent efforts to look at this aspect at the JIATF-S level). Due to the vastness of the JIATF-S area of interest (AOI), this approach requires significant amounts of USCG and USN assets with correspondingly high direct Operations and Maintenance (O&M) costs, as well as indirect capital acquisition costs. The strategic environment that produced this traditional approach, however, no longer exists.

1. The U.S. Strategic Rebalance to the Asia-Pacific Region

Beginning with then-Secretary of State Hillary Clinton's article for *Foreign Policy* in October 2011, and followed shortly thereafter with a President Obama address to the Australian Parliament, the Obama Administration announced a strategic "pivot" toward the Asia-Pacific theater (Scappatura 2014). A Congressional Research Service report observes that this pivot, later re-branded by the Administration as a "rebalancing," appears to have been prompted by

> China's growing military capabilities and its increasing assertiveness of claims to disputed maritime territory, with implications for freedom of navigation and the United States' ability to project power in the region;
>
> the winding down of U.S. military operations in Iraq and Afghanistan; and
>
> efforts to cut the U.S. federal government's budget, particularly the defense budget. (Manyin et al. 2012)

The impact of this rebalancing upon the U.S. Navy is readily apparent in its submission for the President's Budget for FY 2015 (PB-15). At the time of Chief of

Naval Operations Admiral Jonathan Greenert's testimony before the Senate Armed Services Committee on March 27, 2014, 46% (48 of 104) of the Navy's deployed ships were operating in the Pacific theater; revised PB-15 goals project over 54% (67 of 123) of the Navy's deployed ships will operate in the Pacific theater by 2020 (Greenert 2014). This increased naval emphasis on the Pacific theater comes at a cost of reduced naval presence in other theaters, "which in turn could increase risk for the United States in those regions. While the United States does not want to reduce its commitments in the Middle East… high priority capabilities… may be strained by simultaneous demands" in both the Pacific and Middle East theaters (Manyin et al. 2012). It is no big leap to conclude that naval assets to support Operation MARTILLO will come at an extreme premium.

2. Operational Gap: Retirement of the U.S. Navy's Counterdrug Workhorse

Concurrent with this strategic rebalancing, the operational paradigm is also being upended. Throughout its entire history since the end of the Cold War, JIATF-S and its predecessors have been heavily reliant upon the U.S. Navy's FFGs as the primary interdiction asset; however, the last *Oliver Hazard Perry*-class FFG was retired from the fleet in September 2015. While the USCG and other partner nations provide some maritime assets, they lack the complete capability package that the FFG brought to bear. The DTOs constantly innovate and there is some evidence that some are attempting to design and build *fully*-submersibles (Watkins 2011), but current USCG vessels do not have an Anti-Submarine Warfare (ASW) capability. This is just one example of how the lack of a ready frigate replacement leaves a significant interdiction asset gap for JIATF-S.

While the Clinton military drawdown in the mid-1990s, and the start of the Global War on Terror in the early 2000s, marked previous periods of military austerity in the JIATF-S AOI, any reduction in FFG assets was offset by organizational or procedural improvement. The transition from JTF-4 to the JIATF construct helped foster improved intelligence collection (especially of human intelligence sources), fusion, and dissemination. Even in the face of declining resources, "continuing improvements in intelligence networks and operational practices allowed [JIATF-S] to increase its

[tactical] success in interdictions and arrests" (Munsing and Lamb 2011). Several NPS theses continue to contribute to improved efficacy of the few assets provided in terms of:

- Improved probability of detection and classification of semi-submersibles through improved pre-positioning of interdiction assets (Pfeiff 2009);
- Improved probability of interdiction by considering a trafficker as an adaptive adversary and pre-positioning interdiction assets and/or regularly changing interdiction plans accordingly (Bessman 2010, Gift 2010);
- Improved search patterns through the use of probability models to determine where a trafficker may transit the maritime domain (Pietz 2013, Mooshegian 2013, Campos 2014); and
- Development of probability maps of trafficking vessel locations by combining multiple types of intelligence from both sensor-based and human-based sources (Zlatsin 2013).

Even these measures and improvements have a limited effect if the reduction in the amount of assigned interdiction assets is too great. At a certain point, there are insufficient patrol vessels to have meaningful presence in the traditional trafficking lanes. An adaptive DTO may simply wait for a patrol ship to return to port or clear out of an area and then send its GFBs and SPSSs. From FY2007 through FY2009, JIATF-S consistently interdicted about 233t of cocaine per year on average (Kelly 2013). The loss of Forward Operating Base Manta in Ecuador, which had provided domain awareness and presence in the Eastern Pacific south and west of the Galapagos Islands, marked the beginning of a decline in the amount of cocaine interdicted from 154t in FY2010 to 132t in FY2013 (Kelly 2013, Kelly 2014). The 15% decrease in interdicted cocaine during this recent four-year period cannot be explained by changes in the underlying amount of cocaine trafficked alone since the flow estimates for a similar period (FY2010–2012) range from a 9% decrease using consumption-based estimates, to a 27% *increase* using production-based estimates (ONDCP 2012).

3. Irregular Warfare Methods for a New Paradigm

Stemming this reduction in naval assets, however, will not eradicate cocaine trafficking, and putting such a heavy emphasis on direct cocaine interdiction arguably is a piecemeal solution at best. In his 2014 Posture Statement to Congress, General Kelly

lamented, “If bulk shipments are not interdicted before making landfall, there is almost no stopping the majority of this cocaine as it moves through Central America and Mexico and eventually lands on street corners across America” (Kelly 2014).

This observation indicates that Building Partner Capacity (BPC) efforts to increase Central American nations’ ability to interdict cocaine trafficking themselves will be required (Santos 2015). Santos, Bagley, and Shaham (2015) conducted an unclassified study of a hypothetical Weapon of Mass Destruction (WMD) infiltration into the U.S. via existing drug trafficking routes and found that a single capable land partner can effectively replace up to 12 maritime interdiction ships and achieve the same probability of interdiction. However, BPC activities often take years to yield results, and there remains the imbalance of partner nation financial resources to build capacity versus the traffickers’ financial incentives and amassed resources.

This WMD study suggests that the criticality of intelligence—even if only partially correct—and an understanding or awareness of how the threat networks operate is of even greater importance. Dozens of interdiction assets—or a combination of interdiction assets and a land-based BPC effort—are not enough to significantly reduce the chances of a WMD infiltration. Knowledge or intelligence of the threat network, however, provides some of the biggest reductions in this probability, and we must view network exploitation as a battlespace shaping tool to develop this understanding (Santos, Bagley, and Shaham 2015). Since the WMD infiltrator is assumed to use existing drug trafficking routes and organizations, the results of this study and adaptations of the analytical methods it uses may be informative for counterdrug strategies as well.

To simply ask for “more” intelligence collection, however, is not a viable solution. In the author’s experience, the limited intelligence collection and analysis capabilities available tend to focus on “high-value targets” or organizations, but with little or no emphasis on secondary or supporting entities. In the counterdrug context, this would be akin to focusing intelligence collection on *El Chapo* and/or his DTO since he is a high-profile trafficker, but not on lesser-profile supporting or cooperating DTOs that may actually yield better results in terms of overall network disruption.

Due to the strategic rebalance to Asia and a worsening shortfall of operational assets, the JIATF-S J5 Plans and Policy Directorate sponsored this thesis to explore how alternative Counter Threat Network (CTN) approaches (such as those based upon Counter Improvised Explosive Device (C-IED) methods refined during recent operations in Iraq and Afghanistan) may provide viable alternatives to the current paradigm. The underlying alternative hypothesis claims that incorporating a CTN approach—which includes employing alternative non-Major Combat Operation (non-MCO) assets focused on the D&M mission set and improving coordination with service component BPC activities to improve Central American security forces—into Operation MARTILLO should result in greater visibility of the illicit trafficking threat networks, and ultimately in higher overall interdiction effectiveness.

D. SCOPE, GOAL, AND BENEFITS OF STUDY

While an overwhelming majority of current JIATF-S efforts focus on interdicting the physical modes of drug transportation, the GFBs and SPSSs, much less effort at this tactical level is devoted to developing and understanding the human social-management aspect of the trafficking problem, which is a key CTN function (JDSD 2011, USCG 2014). Rather than a tactical question, we seek to address questions of strategic and operational import by showing the benefit of interdicting the DTO social-management layer directly in order to achieve indirect effects on the physical flow of cocaine by removing the resources needed to conduct such movement. In doing so, we provide a potential roadmap for achieving three action items, and supporting a fourth, identified in the 2015 National Drug Control Strategy:

- (6.3.A) improve our knowledge of the vulnerabilities of transnational criminal organizations,
- (6.3.C) target transnational money laundering networks to deny drug trafficking organizations illicit financing and money laundering capabilities,
- (6.3.D) target cartel leadership and their networks, and
- (5.1.B) improve intelligence exchange and information sharing (Obama 2015b).

While the example we use in this thesis specifically addresses 6.3.A and 6.3.D, the same approach can be applied to 6.3.C. With respect to supporting item 5.1.B, this thesis also provides an analytical approach to identifying which parts of the trafficking network may be good candidates for knowledge or intelligence development. Thus, improved prioritization schemes—based coherently on overall threat network vulnerabilities vice independent individual- or DTO-based discriminators—may be used in the development of the Organized Crime Drug Enforcement Task Forces (OCDETF) Consolidated Priority Organization Target (CPOT) list and its associated investigations.

Due to the nature and relative inaccessibility of Law Enforcement Sensitive (LES) data, we do not determine best interdiction plan against a specific cartel, such as the Sinaloa Cartel or the Los Zetas Cartel, nor do we consider restricted data specific to certain individuals, such as *El Chapo*. Rather, we intend to illustrate how our approach can provide insights using hypothetical, open-source data. Therefore, we represent the entire set of cocaine trafficking operations as a single enterprise comprised of DTOs that cooperate to varying degrees. The Drug Trafficking Organization Social-Functional Network Interdiction (DTOSFNI) model introduced in Chapter III lays a foundation upon which more specific and/or sensitive data can be applied in order to provide specific, actionable recommendations to U.S. counter-narcotics planners and operators. Inevitably, there will always be missing data, and the data development section in Chapter IV can help provide some methods by which informed assumptions regarding this type of data can be made.

This thesis also seeks to contribute to an overarching strategic framework under which may nest subsequent operationally- and tactically-focused NPS theses in support of JIATF-S and/or USSOUTHCOM. The main benefit is to illustrate the viability of an indirect approach to the cocaine trafficking problem. While we seek to show how certain types of DTOs or personnel may be more lucrative targets for interdiction, we do not make any assumptions on how to execute such an interdiction. However, the results of this study should help inform JIATF-S and USSOUTHCOM decision-makers on what types of capabilities to request in the Program Objective Memorandum (POM) budgeting

process, and identify typical nodes in the threat social network upon which to begin further knowledge development and exploitation.

E. SOCIAL-FUNCTIONAL NETWORK DESCRIPTION

Our effort explores how the interdiction or disruption of a social network may affect the DTO functional workflow process, or workflow processing rate, for moving contraband through the system. We use open-source data to define a general workflow model along with and geographical routing and typical transportation assets, and to define a single social network of cooperating DTOs to represent the entire cocaine trafficking enterprise (i.e., no major competitors exist in this scenario). This approach considers the following questions:

- WHAT is the threat's driving motivation or goal?
- HOW is this goal achieved operationally?
- WHO is controlling and/or resourcing the operation?

For the purposes of this thesis, the WHAT is essentially this: to make money via the sale of cocaine. Drug traffickers create revenue through arbitrage and physically moving an illicit commodity from its source closer to the point of consumption. The measure of interest in this model is the steady-state maximum net revenue, or profit, of the system in terms of USD per month. This profit is driven primarily by the amount of cocaine flow that actually reaches the U.S. homeland (and its associated street market).

The HOW comprises a certain *process*, or sequence of operations and/or actions, that must be taken in order to achieve the traffickers' goal. This operational process follows a general pattern, or workflow, due to the physical nature of the commodity itself, the geography across which it must be transported, and the various modes of transport used to transport it. We represent this workflow as a functional network that captures the drug flow northward to the U.S.

In general, these types of tasks cannot be accomplished without some sort of human-in-the-loop control mechanism. In this case, the control mechanism is a set of human managers or actors WHO provide resources that enable the functional workflow

tasks to be accomplished. We define a social network representing a single generalized Mexican cartel, along with its ancillary allies and enabling organizations throughout South and Central America and Mexico. Once integrated into a single model, we interdict the social network and measure the impacts upon the functional network throughput. The following sections describe the functional and social sub-networks, along with the overall combined social-functional network.

1. A Representative Functional Trafficking Network

Figure 6 is a general representation of the overall threat functional workflow network. While this appears to be a single network, there are two distinct halves: 1) the drug workflow side, and 2) the financial remittance workflow side. Some tasks or actions may not follow this exact sequencing; for instance, some laundering may occur within the United States prior to "exit." While not shown in Figure 6, there would be several feedback links from the financial workflow side to the drug workflow side that signify the "reinvestment" of profit back into the commodity-transport operation.

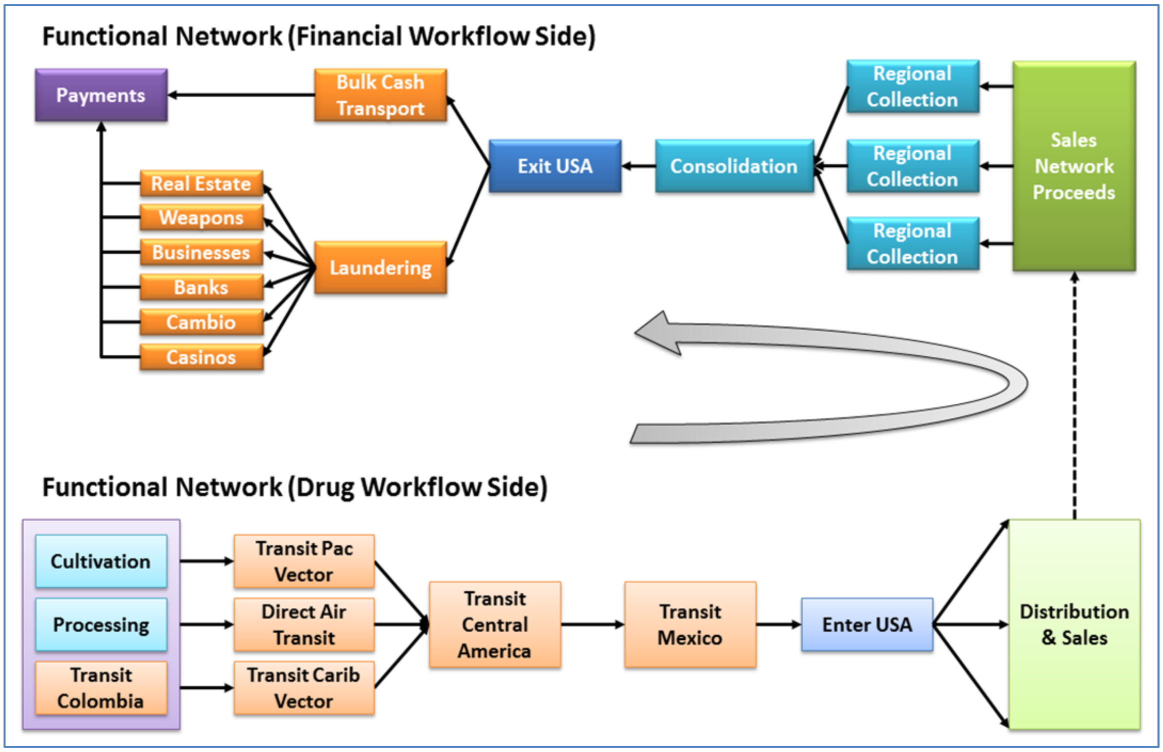

Figure 6. Overall Drug Trafficking Functional Network

A conceptual overview of the overall cocaine trafficking enterprise with a counter-clockwise flow is shown here. The overall functional network includes a Drug Workflow side (Left-to-Right flow in the lower part of the figure), which moves physical cocaine product from South America to the United States, and a Financial Workflow side which moves drug remittances from the United States to South America (Right-to-Left flow in the upper part of the figure). Each of the boxes represents a task or action to transport narcotics in one direction (toward the U.S.) or bulk cash and other monetary instruments in the opposite direction (toward Central and South America). The solid lines indicate logical connections between functions. The dotted line on the right indicates a transactional conversion of cocaine into cash. In general, the color scheme generally defines where a function is accomplished: purple functions in South America, orange functions in Central America and Mexico, blue functions across the U.S.-Mexico border, and green functions in the U.S.

While the entire network is shown for contextual purposes, this thesis focuses on the drug workflow half of the functional network, as there is more open-source information available regarding this part of the enterprise and the methods of cocaine transit are relatively limited. However, the same methods used in this thesis can be applied to the financial portion of the enterprise if LES data were to be made available. The drug workflow functional network (FNet) is shown in greater detail in Figure 7.

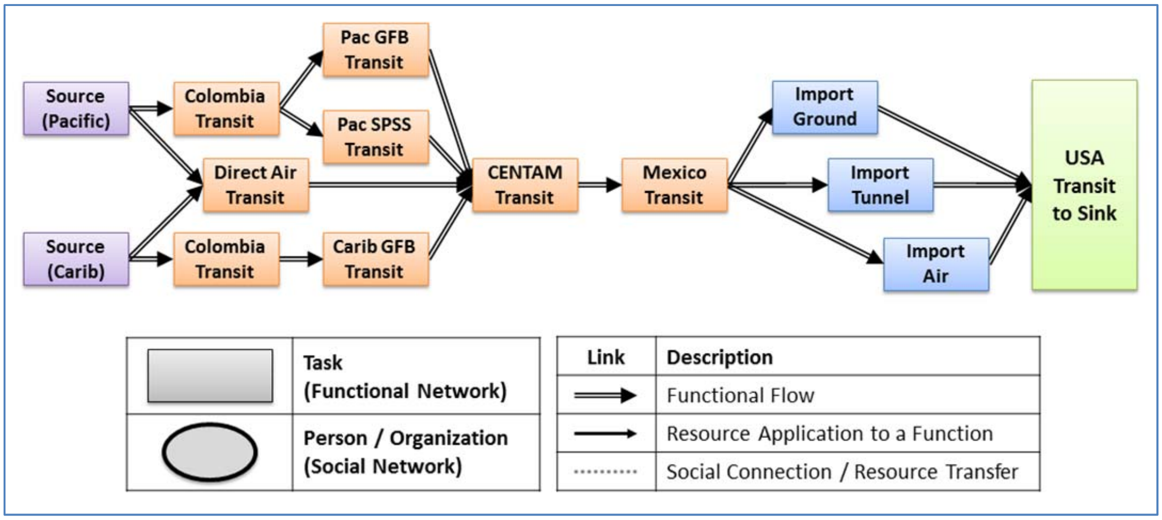

Figure 7. Detailed Drug Workflow Functional Network

A detailed blowup of the Drug Workflow side of Figure 6 using the same color convention is shown by this graphic. Beginning on the left, the functional network has two Colombia cocaine sources, which are geographically separated and feed either the Pacific Vector or the Caribbean Vector. Cocaine from each source can be moved to the respective coastline via truck or can be directly airlifted to Central America. Omitted for clarity is a "Trans-Colombia Transit" function, which airlifts cocaine from a source to its opposite coastline (i.e., from Pacific source to Caribbean coastline). With the exception of the three Pac and Carib transit tasks and the three blue Import tasks—which are unimodal—all tasks shown are aggregated multi-modal tasks. The USA Sink, or final destination, is geographically located in Phoenix, Arizona. The double-line arcs represent logical connections between the functions, which conduct the physical flow of cocaine.

The two geographically-separated sources in Colombia roughly represent the three largest cultivation departments that feed the two major trafficking vectors: Nariño and Putumayo in southwest Colombia primarily feeding the Pacific vector, and Norte de Santander in northeast Colombia primarily feeding the Caribbean vector. The USA Sink, or final destination, is geographically located in Phoenix, Arizona.

The double-line arcs, or arrows, represent logical connections between functional nodes and involve no physical movement. In geo-physical terms, the arcs in Figure 7 represent transfer locations, such as warehouses, airstrips, river mouths, etc.

Each node, or box, of the FNet represents a movement task to be accomplished. Entering a node signifies that a load of cocaine is located at a geographic point of departure and is ready for transit. Exiting a node signifies that the load of cocaine is located at a geographic destination and is ready for the next level of transport. We

incorporate this geo-physical aspect into the model by splitting each functional node into its entry and exit sub-nodes (see Figure 8). The physical movement of cocaine occurs between these sub-nodes over one or more resource-specific directional arc(s). All further discussion of FNet arcs refers specifically these split-node arcs.

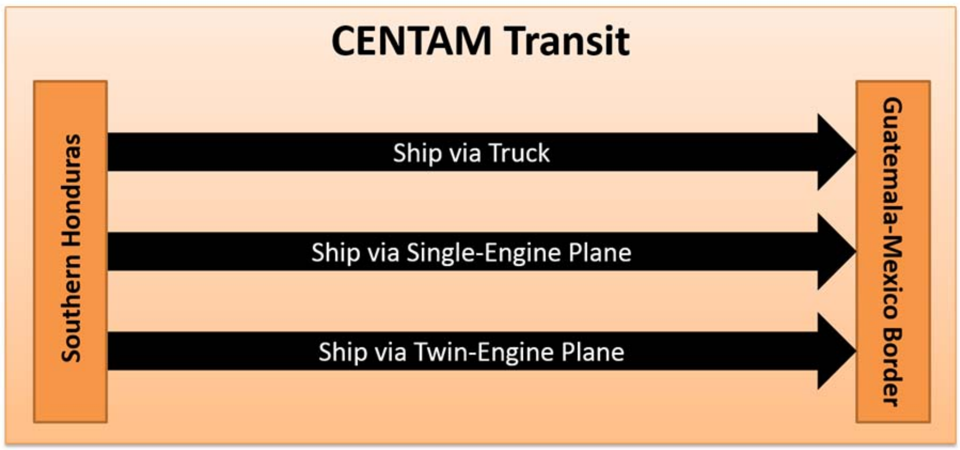

Figure 8. Detailed Magnification of a Functional Network Node

This magnification is an example of a typical FNet task node that is split into two geographical sub-nodes connected by one or more resource-specific directional arcs. Each FNet node encompasses physical movement of cocaine from one geographical location to another via one or more modes of transit. In this case, cocaine can move from the "Southern Honduras" sub-node to the "Guatemala-Mexico Border" sub-node via any combination of trucks, single-engine aircraft, or twin-engine aircraft. The next functional node in the supply chain, "Mexico Transit," would have a corresponding "Guatemala-Mexico Border" sub-node as its entry point. For the purposes of this thesis, the term "FNet arc" refers to the split-node connecting arcs, as depicted here.

Referring back to Figure 7, Pacific vector transit occurs via either SPSS or GFB replenished mid-route by a Logistic Support Vessel (LSV) due to the longer travel distances. Caribbean vector transit only occurs via GFB (no LSV support required). Transit through Central America and Mexico is multi-modal, but these are not separated due to the common geography of the routes. Importation across the U.S.-Mexico border is again split due to the distinct nature or routing of the disparate transit modes. Ground importation is multi-modal, but only for trucks and automobiles. Air importation is multi-modal, but only for single-engine, twin-engine, or ultralight aircraft which require an airfield and/or dirt strip.

The functional drug workflow network is a simplified abstraction due to the relative inaccessibility of LES data and a desire to keep this thesis unclassified. The following is a summary of key assumptions for this part of the model:

- Our hypothetical DTOs use Colombia as the only source country for U.S.-bound cocaine.
- Baseline steady-state cocaine source production and maximum non-interdicted network throughput is set at 53t per month based upon the intent of the traffickers to move all of the estimated annual cocaine production (roughly 633t per 2012 ONDCP estimates).
- SPSSs are restricted to operations in the EPAC vector, and route from Colombia to Honduras.
- GFBs using the EPAC vector take a circuitous route toward the Galapagos Islands before heading northward to Central America. This requires refueling and replenishment at sea via a Logistic Support Vessel (LSV). GFBs using the WCARIB vector do not require LSV support.
- Only air and maritime assets can transport cocaine from Colombia to Central America. Only air and ground assets can further transport cocaine through Central America, Mexico, and into the U.S.

Additional assumptions with respect to transportation asset types and capacities can be found in Chapter IV and/or Appendix A.

2. A Representative Social-Management Network

Figure 9 is a depiction of a generalized cocaine trafficking drug operation, which itself is a conglomeration of several DTOs, which include cooperating DTOs that specialize in certain tasks in the functional network. As a whole, this Social-Management Network (SNet) manages the resources and assets to be used in the FNet. The nodes in Figure 9 represent DTOs with different roles within the SNet. Each DTO node has a supply of resources, such as GFBs, SPSSs, aircraft, trucks, and/or automobiles. We assume that each DTO has an unlimited operating budget for the purposes of this thesis.

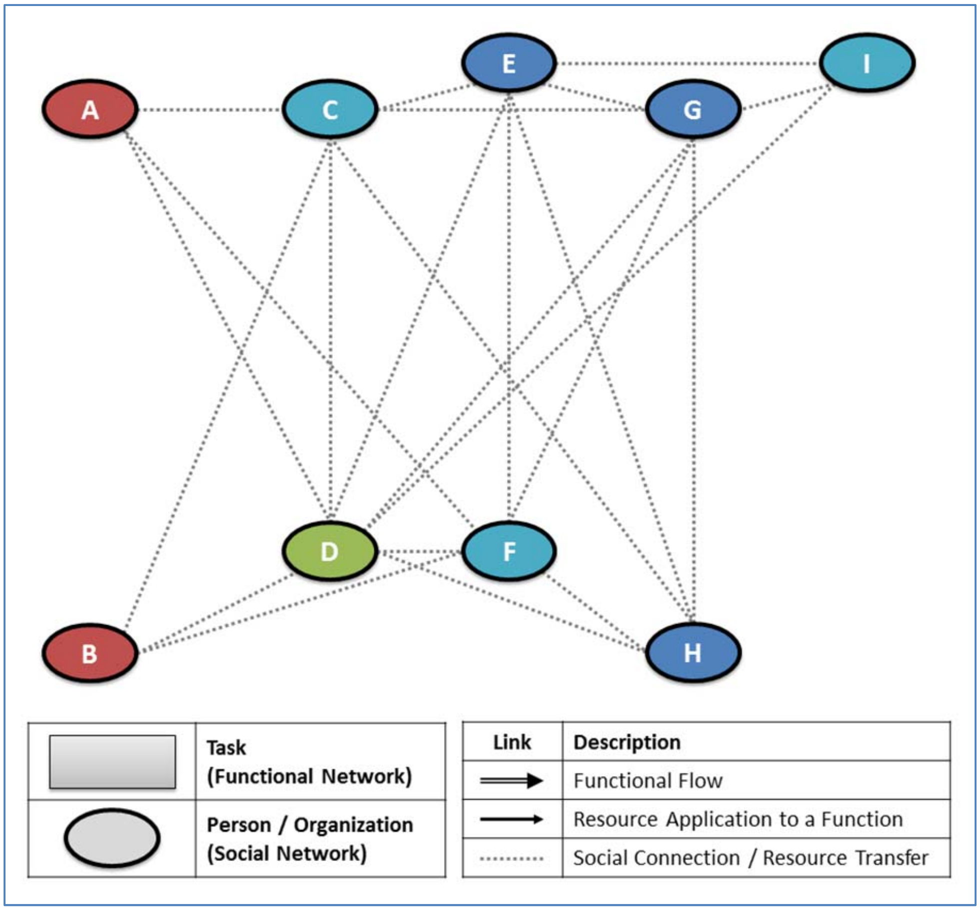

Figure 9. Generalized Cocaine Trafficking Social-Management Network

Red nodes (A and B) indicate source-zone DTOs that focus on cocaine transport from the South America sources to Central America. Light blue nodes (C, F, and I) indicate intermediate-level DTOs that primarily focus on cocaine transport through Central America and Mexico. The green node (D) indicates a money laundering organization that has minimal cocaine trafficking activity but can enable transfer of resources between disconnected social nodes. Dark blue nodes (E, G, and H) indicate the high-level Mexican DTOs that form the core of the cartel. The links indicate relationships between two DTOs, along with possible direct resource transfer between them.

The source zone DTOs (A and B) provide resources to transport the bulk of processed cocaine from sources in Colombia to Central America. Due to the geographic dispersion of the coca growing regions, DTO-A focuses on transit through the EPAC vector while DTO-B focuses on transit through the WCARIB vector. While the distinction is not exclusive, as a small portion of each DTO's efforts may encompass the opposite vector, it should be noted that DTO-A has little incentive to operate in the Caribbean vector since it has little follow-on supply-chain presence beyond the northeast

Colombian coastline. Note that these two DTOs do not have a direct link or arc. This represents an adversarial or competitive situation between the two DTOs and there is no direct cooperation whatsoever.

The intermediate-level DTOs (C, F, and I) primarily provide resources to transport cocaine through Central America, Mexico, and/or into the U.S. While these DTOs utilize various modes of transit that include aircraft, trucks, automobiles, or some combination thereof, some of them may specialize in certain modes. For instance, DTO-I owns a trucking company and engages in cross-border trade, while DTO-F owns a trucking company *and* an air cargo company.

Node D represents a *Money Laundering Organization* (MLO), a special entity that handles most, if not all, of the money generated by the cocaine trafficking enterprise and uses various methods to launder the revenues (usually obtained in the form of bulk cash). Node D does traffic some cocaine and technically would be considered a combined MLO-DTO, but is labeled strictly as "DTO-D" for this thesis. This entity would have a more prominent function if we were to consider the overall trafficking functional network (Figure 6); however, for this instantiation of the drug workflow portion of the functional network, it essentially handles disbursement of money across the social network. We indirectly model this function by allowing resources to "pass through" DTO-D with relative efficiency.

The cartel-level DTOs (E, G, and H) are the informal leaders of the enterprise. These DTOs wield significant power in the network due to their geographic location in Mexico, acting as gatekeepers to the lucrative U.S. market. No other DTO can traffic cocaine into the U.S. without the blessing, or at least ambivalence, of the cartel DTOs. These three DTOs form a strong "Simmelian tie" triad as described in Chapter II. Of note, DTO-G is highly security-conscious, preferring to work behind-the-scenes to overt, exploitable activity in the functional network. Instead, DTO-G has a supply of excess resources that act as a reserve for the rest of the network. DTO-H overwhelmingly uses tunnels under the U.S.-Mexico border to import cocaine, while DTO-E is the most active of the three across the intermediate segments of the functional network "supply chain." There exists significant U.S. political interest in taking down one or more of these cartel-

level DTOs, especially DTO-G, due to the high levels of violence and corruption they cause so close to the U.S. homeland.

A summary of these DTO roles and their associated mindset, or agenda, is shown in Table 2. These roles and mindsets are also used to develop the hypothetical data as described in Chapter IV.

Table 2. DTO Roles and Mindsets

DTO	Role(s)	Mindset
A	Source Transit	Primary focus on transport via the EPAC vector.
B	Source Transit	Primary focus on transport via the WCARIB vector, with lesser focus on the EPAC vector. Uses some aircraft.
C	Intermediate Transit	Primary focus on transit through Central America and Mexico via a mix of ground-based and airborne modes.
D	Intermediate Transit, Money Laundering	Ships exclusively via aircraft.
E	Cartel Leadership	Vertically integrated; most active cartel DTO along entire trafficking pipeline.
F	Intermediate Transit	Owns air cargo company and trucking company.
G	Cartel Leadership	Highly security conscious and prefers to operate behind-the-scenes with minimal overt activity. High U.S. political desire to interdict this DTO.
H	Cartel Leadership	Primary focus on importation. Significant use of cross-border tunnels from Mexico to US.
I	Intermediate Transit	Ships exclusively via its own trucking company.

A DTO's role is an indicator of its association to the FNet geography and of its resourcing level relative to other DTOs, while a DTO's mindset is an indicator of how it prefers to operate. As an example, a Source Transit DTO generally operates close to Colombia, while the mindsets shown indicate in which vector a given Source Zone DTO will usually operate.

The dotted lines in Figure 9 indicate bidirectional arcs between nodes, and represent a relationship between two DTOs. This relationship allows the transfer of assets between DTOs, subject to a trust coefficient and to physical limitations (for instance, a SPSS cannot be transferred from DTO-A in Colombia to land-locked DTO-D in Mexico even though they share a connecting arc). This *trust coefficient* indicates the percentage

of assets that a source DTO is willing to share with a given destination DTO, thus representing the capacity of a given social arc.

The social network is also a simplified abstraction due to the same reasons given for the functional network. The following is a summary of key social network assumptions:

- The DTOs identified are the only ones operating in this space.
- All relationship arcs and trust coefficients are known.
- There are no command and control relationships, meaning DTO-C cannot direct DTO-A on what to do or how to do it. There is only a supplier-buyer coordinating level of relationship.

3. The Combined Social-Functional Network

Linking the SNet with the FNet results in the combined Social-Functional Network (SFNet) model shown in Figure 10. This simplified depiction of the SFNet does not necessarily imply that a social node DTO connected to a particular functional node can apply its entire range of resources for that task. For instance, DTO-D connects to CENTAM (Central America) transit, which can make use of both trucks and aircraft, but is only able to apply aircraft to the function. Any trucks needed by CENTAM Transit must be provided by another DTO.

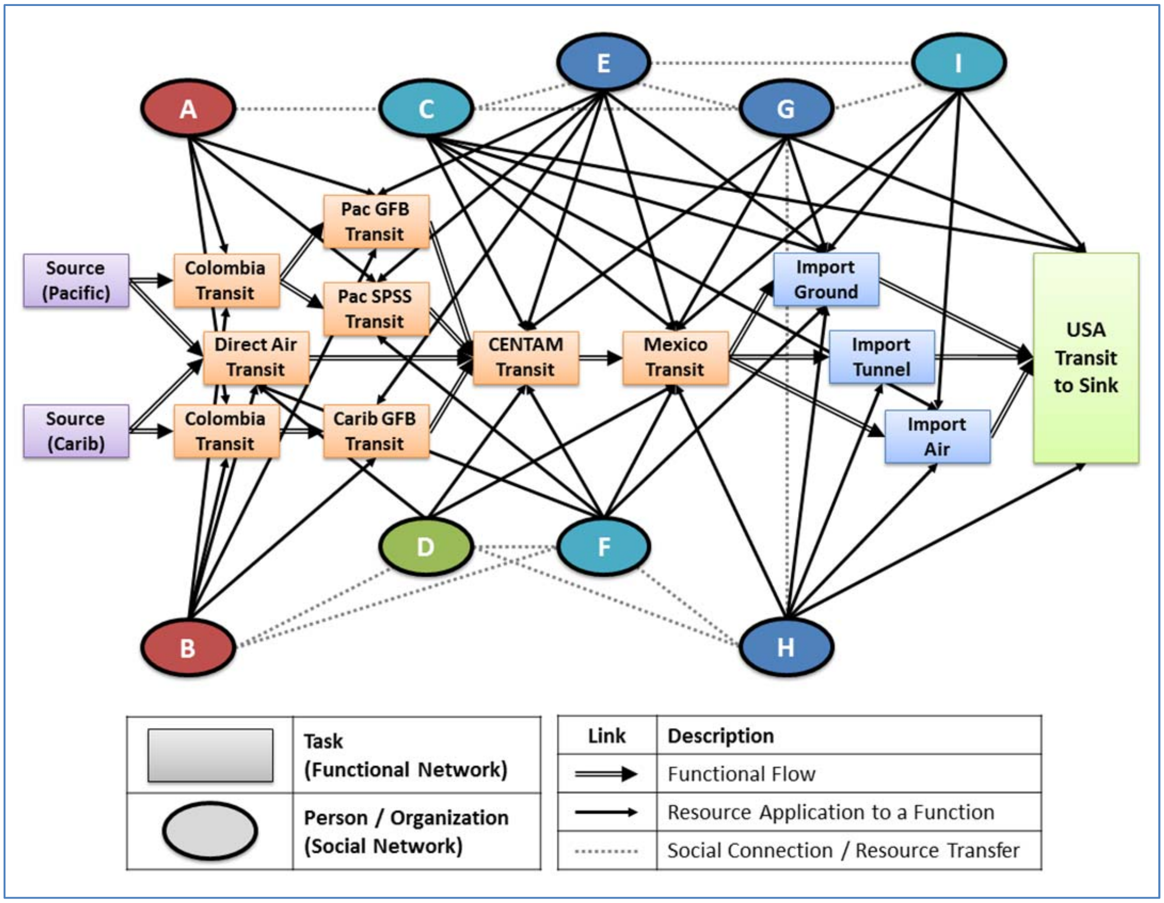

Figure 10. Combined Social-Functional Network

The SNet connects to the FNet via solid resource arcs (some social network arcs are removed for clarity). These arcs represent the possible functions that a given DTO may support given sufficient resources. The removal of a DTO means that any functional nodes to which it is connected do not benefit from the DTO's resource supply. Other DTOs connected to those nodes may apply additional resources to increase flow capacity, but this siphons assets from elsewhere in the system. If a connected DTO does not have enough of a required resource, other DTOs may opt to transfer that resource to the given DTO, which in turn applies the asset to the function.

Without the application of resources from any connected DTO, a function cannot be accomplished. Additional resources applied increase the cocaine throughput capacity of that functional node. In some cases, a DTO may provide all of the direct resources to accomplish a task; in other cases, several DTOs may contribute to the capacity of a task. The total amount of resources applied to each task has a corresponding, but diminishing, effect upon the capacity and throughput of the task. For instance, a single truck assigned to a particular FNet node may be able to carry 0.9t of cocaine, but two trucks assigned

(across all social actors) to the same functional arc may only have a total capacity of 1.7t (an average of 0.85t per truck). We represent each resource-dependent FNet arc capacity as a piecewise linear concave capacity function as described in Chapter III. The relationship of the SNet nodes, FNet nodes, and SFNet arcs is shown in Figure 11.

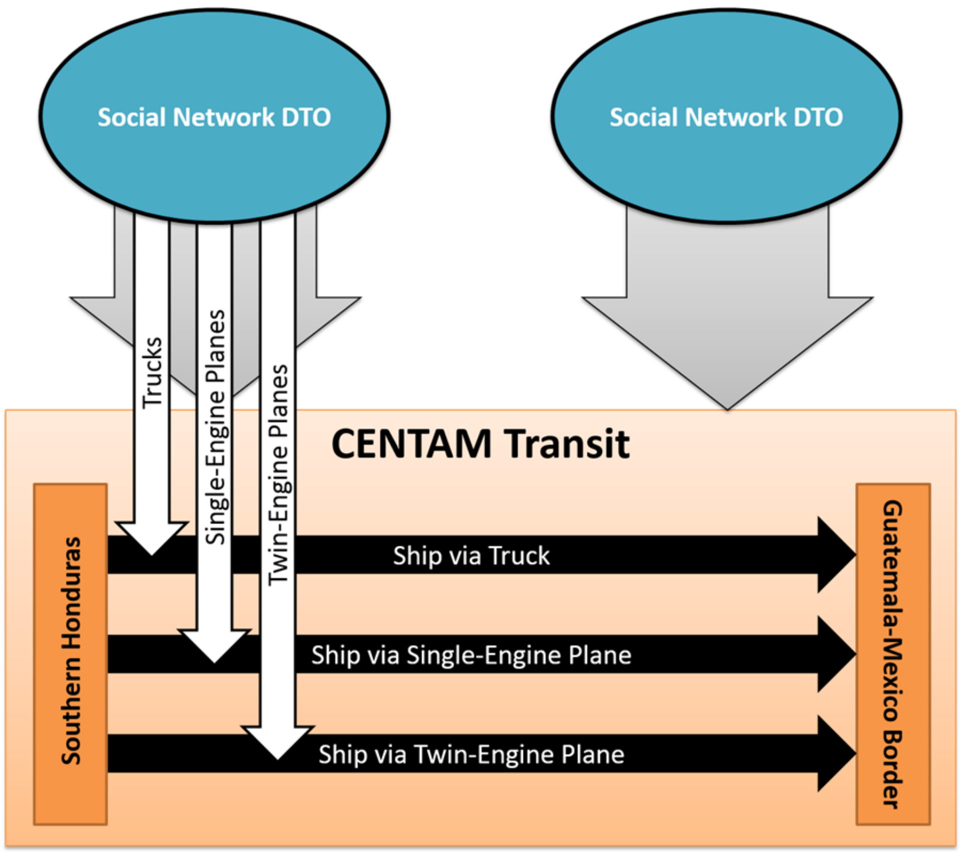

Figure 11. Detailed Magnification of Social Network Nodes and Functional Network Node

This detailed magnification incorporates typical SNet nodes (blue ovals) and SFNet arcs (shown in grey) into the FNet split-node depiction from Figure 8. In this fashion, arcs only connect nodes. In actuality, each connected SNet DTO may apply resources to a node in order to enable resource-specific FNet arc capacities.

The following are key assumptions specific to the SFNet not yet addressed in the SNet and FNet assumptions:

- The un-interdicted SFNet can flow all source cocaine to the U.S. sink.
- No direct interdictions of the FNet portion of the SFNet are allowed.

- Removal or interdiction of a SNet node removes all resources contained in that node; these resources are no longer available for FNet task accomplishment nor for sharing throughout the SNet.

While not explicitly included in this model, each DTO has an unlimited operating budget and will use this budget insofar as this enables the use of resources to push more cocaine through the system.

F. THESIS ORGANIZATION

The remainder of this thesis follows this structure: Chapter II is a review of existing literature in the field; Chapter III presents the network specifics, the attacker-defender model, and the algorithms used to obtain a solution; Chapter IV discusses the instantiation of the problem, to include hypothetical data development, and numerical results from the model; and Chapter V summarizes the research and presents recommendations and conclusions. Appendix A provides detailed data not identified in Chapters I or IV, and Appendix B provides complete results in tabular format.

II. LITERATURE REVIEW

This literature review provides an overview of previous work related to interdiction of drug trafficking or other surreptitious networks. First, we discuss quantitative network interdiction methods. Then, we introduce human-centric concepts used in social network analysis (SNA). Finally, we discuss techniques that draw from both areas and how our work either extends some of these concepts, or fills informational gaps in the research.

A. QUANTITATIVE NETWORK ANALYSIS METHODS

Quantitative counter-narcotics research in support of JIATF-S falls into two main categories: network interdiction and statistical analysis. Network interdiction methods may focus on either disrupting flow through a system or upon capturing a specific conveyance or load of a commodity as it moves through a system. Statistical methods focus on the latter only.

1. Network Flow Problems

Ahuja, Magnanti, and Orlin (1993) provide a thorough introduction to network flow theory and applications across a wide range of fields such as project management, transportation, telecommunications, and supply chain management. They suggest that network flow applications fall into any of three main types:

- the *shortest path problem*, in which the goal is to identify how to most efficiently travel from one point to another;
- the *maximum flow problem*, in which we wish to determine the maximum amount of a commodity that can get through a system given certain capacities; and
- the *minimum cost flow problem*, in which resources or goods reside at various points in the network and need to be delivered to other points in the network in the least costly fashion.

We will draw heavily on the two latter concepts. Additionally, whereas most simple network flow models assume that flow is conserved across every arc, we employ

the concept of *generalized flow*, which makes no such assumption and therefore allows for transmission loss or leakage.

2. Attacker-Defender and Defender-Attacker Network Interdiction Models

Wood (1993) describes an application of simple network interdiction ("max flow-min cut") to USSOUTHCOM counter-drug efforts in which a trafficker attempts to maximize flow through a capacitated network of rivers and roads while an interdictor attempts to minimize such flow by stopping flow on a certain number of arcs. Wood utilizes a set of rewards to "motivate" the trafficker to move through the system, a method we also employ.

Brown, Carlyle, Salmerón, and Wood (2005) describe a two-sided *attacker-defender problem* as a Stackelberg game in which two adversaries move sequentially in a leader and follower relationship. In this case, the attacker (leader) decides which nodes to interdict then the defender (follower), who observes this action, chooses the remaining least cost (or most beneficial) path or route to use. This type of model is appropriately used by an attacker seeking to disrupt the viability of a defender's system or level of profits, which is central to this thesis. Conversely, a *defender-attacker problem* would reverse the sequencing such that the defender acts first and the attacker reacts to such action. This type of approach is useful for solving an optimal defense problem that identifies "the best possible defense given a limited defense budget (Brown et al. 2005)."

The following is a general mathematical variation of the attacker-defender formulation described by Brown et al. In this case, the defender (also known as an operator) is the trafficker, and the attacker is the USG (and its international partners). The defender's problem, more commonly known as the *operator model*, is

$$\max_{y \in Y} \; (r-c)y \tag{1}$$

where (i) y represents trafficker decisions, (ii) r defines the vector of rewards, (iii) c defines the vector of costs and/or penalties, and (iv) the set Y represents the constraints on the trafficking operation, such as arc capacities and transport assets available.

While the defender attempts to maximize net rewards, the attacker attempts to minimize this outcome. When the attacker moves first, followed by the defender's response to that attack, this type of model is a min-max Stackelberg game. Therefore, the bilevel extension of the general formulation (1) applies an attacker variable subject to an attack budget and is represented as $x \in X$. The defender's set of possible actions restricted by interdictions x is represented as *Y*(*x*). The attacker's problem, MIN-MAX, is

$$\min_{x \in X} \max_{y \in Y(x)} (r - c) y. \tag{2}$$

Note that operator model (1) is the *inner* problem for attacker's problem (2). As we seek insights into the trafficking problem and not necessarily *the* optimal solution, our formulation and approach (as described in Chapter III) primarily uses an extension of (1) with an enumeration of a range of results that may or may not capture the automated result that a full two-sided formulation might obtain.

Brown et al. further describe even *three-sided (or trilevel)* defender-attacker-defender applications to critical infrastructure defense, including how such planning is manifestly different from military applications when discussing the vulnerability of a commercial entity's supply chain. Their supply chain example is analogous to our functional model, but differs in that efficiency is sought in a commercial supply chain in order to reduce cost, thus leaving the chain vulnerable to attack, whereas the trafficking model incorporates several redundancies due to the inherent risk of discovery and arrest.

Introduced in Chapter I, several recent NPS theses present variations on the basic attacker-defender or defender-attacker approaches and focus exclusively upon detecting and interdicting a specific seaborne conveyance. Pfeiff (2009) combines a traditional defender-attacker model with platform-specific probabilities of detection of a SPSS in order to determine optimal placement of said search platforms. Gift (2010) considers an adaptive evader (trafficker) who learns of interdictor asset placement using different learning policies and measures the effect on attacker efficacy. Bessman (2010) also considers an adaptive evader, but in this case the evader reevaluates his remaining path options at each step along his way, taking into consideration knowledge obtained *en route*.

3. Statistical Approaches

Another set of NPS theses apply statistical methods to improve ultimate counterdrug interdiction prospects, but are not network interdiction methods *per se*. In general, the following approaches consider the problem from a slightly different angle: that of how to optimize interdiction prospects by incorporating an intelligence or informational aspect into the model. Zlastin (2013) uses a Bayesian model to fuse together different types of incomplete data to reduce the uncertainty volume around the estimated current position of a particular trafficking target. Mooshegian (2013) uses Multivariate Adaptive Regression Splines developed by Pietz (2013) to determine probabilities of where a located target may next travel; essentially this is an advanced version of navigational dead-reckoning. Campos (2014) takes the output of this probability model as inputs into an optimization model in order to improve the chances of interdictor acquisition and prosecution of the target.

Much of this and other network interdiction work focuses on the tactical or execution level, and addresses the actual trafficker's modes of transportation and even specific conveyances. However, there appears to be a gap in research at the operational or strategic levels that consider how the trafficker actually manages or controls that particular mode of transportation, and at which level (tactical conveyance or operational-strategic management) an interdiction may have more impactful results.

B. SOCIAL NETWORK ANALYSIS

Social network analysis is a more human-oriented methodology than the quantitative methods previously introduced. This is not to say, however, that SNA is purely non-quantitative. In fact, SNA shares with network flow theory many graph theory terms and concepts, and uses certain simple quantitative metrics.

1. Traditional SNA Methods

Degenne and Forsé (1999) describe classic *social network analysis* as a set of methods used to systematically study social structures—by focusing on understanding or discovering patterns of behavior, links or relationships, position, and power among and

between individuals within those social structures. These methods measure the extent to which an individual is connected to other individuals within a group (*centrality*). This may manifest itself in terms of how many connections an individual has to others (*degree centrality*), or the proportion of shortest paths between disparate third-party individuals that must pass through the individual of interest (*betweenness centrality*). They also expound upon the concept of *flow betweenness*, a type of centrality measure that uses flow—be it communication or resources—as the betweenness metric to determine important individuals in the network. While this last concept will be useful in this thesis, Degenne and Forsé make no mention of determining the importance of an individual in terms of what the social group is attempting to accomplish.

Krackhardt (1998) explores the structural and dynamic differences between dyadic and triadic relationships first introduced by George Simmel. The *dyad*, a direct relationship between two people that can be characterized as either weak or strong, is the smallest form of network relationship. A dyad may be very strong as long as its two members mutually benefit, but it is also quite vulnerable since removing only one actor eliminates the entity. A dyad also affords either actor significant bargaining power within the relationship. A *triad*, on the other hand, has a different set of dynamics not simply due to the structural addition of a third entity. In a triad, the members have less individual leverage as any threat to leave the group results in a surviving dyad, which may be quite powerful compared to the individual. This leads to behavior and choices that help the group as a whole, rather than a single individual. This eventually helps mediate conflict within the group and can make it a much more stable and resilient structure than a dyad. Krackhardt further describes a coclique Simmelian tie in which "two people… are reciprocally and strongly tied to each other [as in a dyad] and… they are reciprocally and strongly tied to at least one third party in common (Krackhardt 1998)." Krackhardt shows that the Simmelian tie adds power and durability beyond that of a dyad and will last longer than other forms of ties. Thus, our pseudo trafficking social network has at its core a triad of cartel-level Mexican DTOs.

Sparrow (1991) suggests that criminal intelligence analysis would benefit greatly from SNA techniques, and that traditional "lead-following" techniques are ultimately

ineffective. Sparrow quotes Lupsha (1980): “In terms of the war against organized crime, this approach has caused some analysts to wonder if individual-oriented prosecutions merely help to open the promotion ladder… while the group and the crime [activities] they engage in continues.” This bodes ominously for the current Operation MARTILLO implementation in which significant law enforcement time and effort is expended in “turning” captured low-level GFB or SPSS crew to gain information on a much larger narcotics network. Sparrow also highlights that “criminal network data is inevitably incomplete,” meaning that existent links or nodes will be unobserved, and he points out that little research had been accomplished to explore this issue up to that time.

2. Enhancements to SNA

W. Nesbitt (2006) helps to address this shortcoming in traditional SNA by introducing quantitative network-interdiction algorithms and then incorporating a set number of hidden arcs, which represent missing information, into the solution. Of note, one of the three example networks Nesbitt analyzed was an international smuggling network with a chain-like network structure.

Erlacher (2013) combines SNA and the Special Operations Targeting Process (SOTP) to provide an improved methodology for “framing, describing, analyzing and proscribing solutions in complex social conflict environments.” He uses the CARVER (criticality, accessibility, recuperability, vulnerability, effect, and recognizability) analysis method, whereupon the analyst makes value distinctions based upon mission intent, in order to better identify potential interdiction options. While Erlacher’s approach brings an operational focus to SNA, the value distinctions he references, however, are often subjective judgments; the overall approach remains focused on the existence or viability of the social group itself, not on what the group is attempting to achieve.

C. COMBINED MODELS

An extension of Sparrow’s suggestion of merging two different worlds to find synergies is the idea of combining two previously unrelated concepts into a single model—a social network and a project flow network, for instance—thus bringing what the social group is attempting to accomplish into consideration. P. Nesbitt (2012) first

applies this concept to a specific example of how to delay the development of an Iranian nuclear weapon, not by direct interdiction of the workflow process, but instead by interdiction of the manager and/or resources applied by those managers that facilitate the execution of that workflow. P. Nesbitt's model, Adversarial Goal Interdiction (AGI), is a mixed integer linear program that explores attacker-defender interdictions against the social network nodes.

We further expand upon P. Nesbitt's work by applying a similar approach to the cocaine trafficking problem. Nesbitt's nuclear weapon problem benefits from a functional model which is based on well-understood physics and engineering project information (e.g., the enrichment of uranium can be accomplished only so many ways and a ballistic missile must adhere to certain aerodynamic and guidance principles). While it also has a well-defined functional model, the cocaine trafficking problem presents more complexity due to the inherent lack of data and the secretive nature of highly-adaptive criminal organizations.

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III. SOCIAL-FUNCTIONAL INTERDICTION MODELING

This chapter first introduces the DTOSFNI model formulation, which is a parameterized operator model similar to formulation (1) from Chapter II that attempts to maximize trafficker profit. We then solve the attacker's problem (2) through enumeration of one-, two-, and three-DTO interdiction options.

A. DRUG TRAFFICKING ORGANIZATION SOCIAL-FUNCTIONAL NETWORK INTERDICTION MODEL FORMULATION

The Drug Trafficking Organization Social-Functional Network Interdiction (DTOSFNI) model is a linear program representation of the conceptual SFNet. The trafficking enterprise seeks the optimum distribution of resources to maximize *steady-state* monthly financial profit in the equivalent of millions of U.S. dollars (USD). It allows the enterprise to decide what types of resources to apply to which functional tasks, and whether or not to shift resources between DTOs. The model rewards the traffickers for moving an amount of cocaine to each successive level in the network, reflecting the increasing value of cocaine as it nears the U.S. market. The model also imposes costs to employ a given type of resource for a given task, as well as penalties for shifting resources between social entities and for attempting to move resources through, or apply resources from, an interdicted social node. The DTOSFNI formulation is now presented in mathematical programming format.

1. Sets

FN	Functional Nodes
SN	Social Nodes
$SFA \subseteq FN \times SN$	Social-Functional Arcs
$FA \subseteq SFA$	Subset of SFA representing arcs strictly between FN
$SA \subseteq SFA$	Subset of SFA representing arcs strictly between SN
R	Resources

2. Indices

$i \in FN$	Functional node (alias j)
$n \in SN$	Social node (alias n')
$(i, j) \in FA$	Arc directed from functional node i to functional node j
$(n, n') \in SA$	Arc directed from social node n to social node n'
$a \in SFA$	Resource-specific social-functional arc: $FA \cup SA \cup (n, i, j)$
$r \in R$	Resource type representing a specific mode of transport
bp	Breakpoint for $cost$ parameter

3. Parameters and Data

$reward_{i,j,a}$	Financial benefit of transporting cocaine from functional node i to functional node j using social-functional arc a [USD millions/metric ton of cocaine]
$supply_i$	Monthly cocaine supply at functional node i [metric tons/month]
$r\_supply_{n,r}$	Resource supply r available at social node n
$trust_{n,n'}$	Trust coefficient directed between social nodes n and n'
$cost_{n,i,j,a,r}$	Incremental cost to apply resource r from social node n to social-functional arc a between functional nodes i and j [USD millions/unit]
$intercept_{i,j,a,bp}$	Intercept of linear bounding function for given breakpoint bp based on the total resources applied to social-functional arc a between functional nodes i and j
$slope_{i,j,a,bp}$	Slope of linear bounding function for given breakpoint bp based on the total resources applied to social-functional arc a between functional nodes i and j
s_pen	Penalty for attempting to send resources through, or from, an interdicted social node [USD millions]
$s\_friction$	Penalty to prevent unnecessary movement of resources between social nodes [USD millions]
$\hat{x}_n$	Interdiction parameter; Equals 1 if social node n is interdicted, 0 otherwise

4. Decision Variables

$RES_{n,i,j,a,r}$	Apply resource r from social node n to social-functional arc a between functional nodes i and j
$RES\_XFER_{n,n',a,r}$	Transfer of resource r from social node n to social node n' via social-functional arc a
$FLOW_{i,j,a}$	Cocaine flow from functional node i to functional node j via social-functional arc a [metric tons/month]

5. Formulation

$$\begin{aligned}
\max \quad & \sum_{\substack{(i,j,a)\\ \in FA}} reward_{i,j,a} FLOW_{i,j,a} \\
& - \sum_{n \in SN} \sum_{\substack{(i,j,a,r)\\ \in SFA_n}} cost_{n,i,j,a,r} RES_{n,i,j,a,r} \\
& - s_pen \sum_{n \in SN} \hat{x}_n \left(\sum_{\substack{(i,j,a,r)\\ \in SFA_n}} RES_{n,i,j,a,r} + \sum_{\substack{(n',a,r)\\ \in SA_n}} RES_XFER_{n,n',a,r} \right) \\
& - s_friction \sum_{n \in SN} \sum_{\substack{(n',a,r)\\ \in SA_n}} RES_XFER_{n,n',a,r} \qquad (3)
\end{aligned}$$

$$\begin{aligned}
\text{s.t.} \quad & FLOW_{i,j,a} \le intercept_{i,j,a,bp} \\
& + slope_{i,j,a,bp} \sum_{\substack{(n,r):\\ (i,j,a,r)\\ \in SFA_n}} RES_{n,i,j,a,r} \qquad \forall (i,j,a) \in FA, bp \qquad (4)
\end{aligned}$$

$$\sum_{\substack{(j,a)\\ \in FA_i}} FLOW_{i,j,a} - \sum_{\substack{(j,a):\\ (i,a) \in FA_j}} FLOW_{j,i,a} \le supply_i \qquad \forall i \in FN \qquad (5)$$

$$\begin{aligned}
& \sum_{\substack{(n',a):\\ (n',a,r)\\ \in SA_n}} RES_XFER_{n,n',a,r} - \sum_{\substack{(n',a):\\ (n,a,r)\\ \in SA_{n'}}} trust_{n',n} RES_XFER_{n',n,a,r} \\
& + \sum_{\substack{(i,j,a):\\ (i,j,a,r)\\ \in SFA_n}} RES_{n,i,j,a,r} \le r_supply_{n,r} \qquad \forall n \in SN, r \qquad (6)
\end{aligned}$$

$$FLOW_{i,j,a} \geq 0 \qquad \forall (i,j,a) \in FA \qquad (7)$$
$$RES_{n,i,j,a,r} \geq 0 \qquad \forall n \in SN, (i,j,a,r) \in FA_n$$
$$RES\_XFER_{n',n,a,r} \geq 0 \qquad \forall (n,n',a,r) \in SA$$

6. Discussion

The objective function (3) assesses profit, which breaks into an additive reward component based on amount of cocaine moved, and detractive cost and penalty components based on the actual and/or attempted application or transfer of resources. Each resource contribution constraint (4) limits the maximum FLOW capacity on a given functional arc FA. Each balance-of-flow constraint (5) ensures that, given a supply of cocaine is available from a predecessor functional node and sufficient resources are applied to move that cocaine to a successor functional node, the commodity will flow through the functional network. Each balance-of-resource-flow constraint (6) limits the amount of resources a particular DTO can apply to functional tasks to the sum of its initial resource supply and any flow it receives from other DTOs, less what it transfers to any other DTO. The $trust_{n,n'}$ coefficient described in Chapter I directly affects this constraint and restricts the unfettered flow of assets throughout the social network. Domain restrictions (7) list all non-negativity constraints for the decision variables.

We approximate each resource-dependent FNet arc capacity by a concave piecewise linear function of the resources applied as shown in Figure 12. Each capacity function is specified by three values, one at each of three (non-zero) "breakpoints" at which the slope changes; at the origin, zero resources are applied and there is zero capacity, which gives us a fourth breakpoint. From these breakpoint-value pairs we derive the slopes and y-intercepts that define the three linear functions that bound the capacity on that arc.

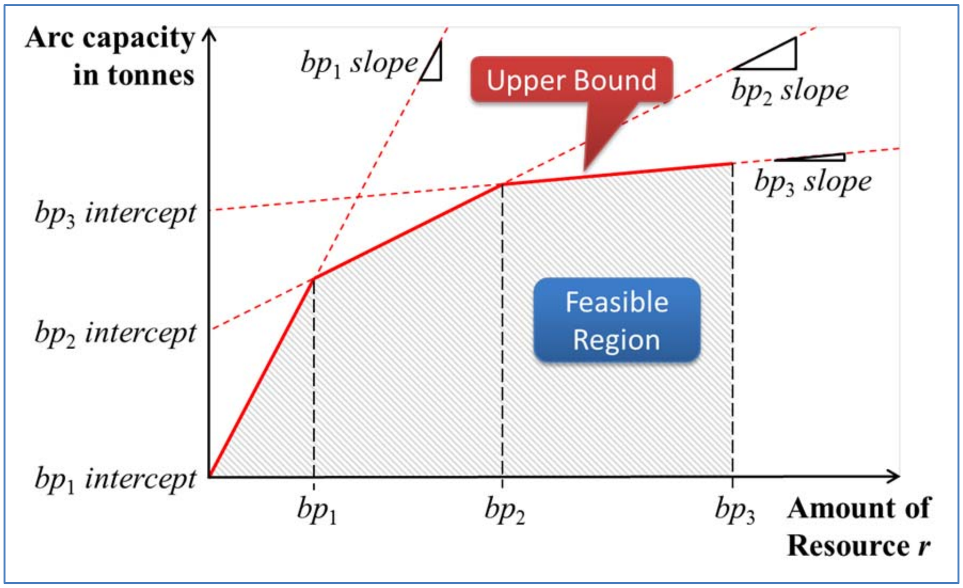

Figure 12. Piecewise-Linear Capacity Function for a Typical Functional Network Arc

Each red dashed line is an upper bound on the capacity. Note that bp_3 also denotes the upper resource limit. Together, the constraints derived from these bounds result in a linear program and a feasible region for allowable cocaine flow across that particular FNet arc. Detailed capacity function data for each resource type and FNet arc, as well as an applied example of this chart, can be found in Appendix A.

B. ENUMERATION OF ATTACKER INTERDICTIONS

We input the DTOSFNI model and data into the General Algebraic Modeling System (GAMS 2015). Due to the relatively small size of the social network (only nine nodes) it is possible to parameterize the interdiction options using a one-sided approach. Since the main purpose of this application of the DTOSFNI model is to aid with developing insights into the trafficking problem, and we are not necessarily looking for the *best* attack plan (such as by the employment of a two-sided attacker-defender model), but rather a set of relatively *better* attack plans that may differ on how well they perform with respect to two metrics: total trafficker reward (explicit to the model) and how much additional overt action by DTO-G a set of interdictions causes with the intent of gathering evidence on DTO-G (a corollary output of the model).

Even with our relatively small social network of nine nodes, complete enumeration of all attacks becomes cumbersome quite rapidly, especially if one attempts to do this manually. Limiting ourselves to only one interdicted node yields nine possible

options. If we interdict any two nodes, we have 36 possible combinations. There are 84 possible combinations of any three nodes. We use an upper limit of three simultaneous or closely-sequenced attacks, not because it is computationally demanding, but because we assume this scenario approaches the maximum capacity of the U.S. counterdrug community. Our enumeration approach follows:

1. Zero interdictions: determine baseline profit and DTO-G activity level results.
2. Single interdictions: determine profit reduction and DTO-G activity level results for individually interdicting DTO-A through -I.
3. Dual interdictions: determine profit reduction and DTO-G activity level results for all pairs of DTOs, such as AB, AC, AD, … , HI.
4. Triple interdictions: determine profit reduction results for all triplets of DTOs, such as ABC, ABD, ABE, … , GHI.

IV. DATA, RESULTS, AND ANALYSES

This chapter begins with a review of the hypothetical data—as well as methods and/or assumptions made in its development—used in this instance of the trafficking problem. This is followed by a review of the results and the chapter concludes with analyses of the results.

A. HYPOTHETICAL DATA AND DEVELOPMENT

Developing hypothetical data that approximates realistic data may be almost as difficult as obtaining real-world data from the outset; however, a methodical approach that begins with "known" data and uses certain intermediate assumptions to derive "unknown" data helps ensure the data instance makes sense. Such an approach is also extremely powerful when "perfect" adversary information is not available, which is inevitably the case with incomplete friendly information or knowledge of TOCs.

We begin our data development by exploiting the geo-physical limitations of cocaine trafficking in the functional network. Because we are dealing with a physical commodity (i.e., cocaine)—with limited sources and sinks—and physical means of transport, there are limited variations of the *process* of moving cocaine to the United States. This physical milieu also effectively channelizes any social entities who wish to enable and/or profit from the transport and eventual sale of cocaine. By exploiting these known geo-physical limitations, we can apply reasonable assumptions with respect to the capacities of the various modes of transport in order to determine a bound on the upper limit of what is possible (i.e., the maximum hypothetical throughput of cocaine) in a non-interdicted base case.

We then use an iterative approach to develop the resource data, by selecting initial resources values, running a maximum flow variation of the DTOSFNI model on subsequently larger subsets of the FNet (beginning with intra-Colombia transit and expanding from there), and observing the results. Any anomalies observed (such as inadequate cocaine supply movement, over- or under-involvement of a particular DTO, etc.) inform the potential need for modifications to the initial data choices. A similar

approach also informs the choice of *behavior parameters*, cost modifiers used to obtain appropriate DTO levels of activity in certain parts of the FNet.

Each of the following sections provides an overview of the main data and assumptions used in this instance of the trafficker problem. Detailed data can be found in Appendix A.

1. Functional Network Cocaine Data and Assumptions

We begin the FNet data development from the "known" ONDCP annual cocaine production estimate of 633t from Chapter I, converting it to an aggregated steady-state monthly supply of 53t. For consistency within the model, we assume all weights are for pure, uncut cocaine. We also assume all production is US-bound and transit is geographically limited to Central America and Mexico. According to ONDCP estimates, the trafficking via the EPAC vector far outpaces that in the WCARIB vector (refer to Figure 1 in Chapter I). We estimated supplies of 34.5t and 18.5t for the Pacific source and the Caribbean source, respectively, as shown in Table 3 using a least squares approximation to known ONDCP data points for the mix of conveyances and their capacities.

Table 3. Functional Network Steady-State Monthly Supply Data

Source Node	Supply (tonnes)	Data Type
Colombia Pacific Source	34.5	Derived
Colombia Caribbean Source	18.5	Derived
Total	53.0	Known

The 53.0t per month steady-state production approximates the ONDCP annual production estimate of 633t. We also assume all production is US-bound and transit is geographically limited to Central America and Mexico. We use a least squares approximation to current ONDCP estimates for the mix of trafficking conveyances and their observed capacities, to derive the monthly supply from each of the FNet source zones.

Without a feedback arc that connects the functional network sink to the sources, as in a traditional maximum flow model, we need a mechanism to "motivate" the cocaine to move throughout the network. This is accomplished by using rewards for every unit of cocaine the traffickers deliver to subsequent nodes in the functional model. Shown in

Table 4 are the rewards used, which approximate the increasing value of cocaine as it nears the U.S. retail market. When combined with total tonnage moved into a zone, this provides gross revenue earned by the traffickers. The difference in market value for any FNet arc is the "marginal" value provided by moving cocaine from one endpoint to the other across that particular arc. These marginal values become the $reward_{i,j,a}$ coefficients used in the objective function of the DTOSFNI model.

Table 4. Functional Network Reward Data

Zone Reached	Value (USD per gram)	Marginal Value (USD per gram)
Source	0	0
South America Coast	5	5
Central America	10	5
Southern Mexico	12	2
Northern Mexico	16	4
U.S. Side of U.S.-Mexico Border	25	9
U.S. Sink	100	75

Data adapted from Stewart (2013) Mexico's Cartels and the Economics of Cocaine. Stratfor Security Weekly (January 3), https://www.stratfor.com/weekly/mexicos-cartels-and-economics-cocaine. The U.S. Sink zone value reflects the retail street price. All other values reflect the wholesale price for a given zone. This set of rewards acts as a mechanism to induce cocaine movement through the FNet.

There also exist certain costs in the FNet that depend on the mode of transport used, where that mode is employed geographically, and on the distance that must be covered over the course of a round trip. In general, there are two parts of the modal cost per unit employed: a fixed cost that includes special operator pay (such as for pilots), and a variable cost that includes O&M (per mile) as well as an amortized acquisition cost. In the case of the SPSS, each vessel is expected to make a single one-way trip, so the amortized cost is the per-unit construction cost of $1 million. The costs used in this instance are not intended to be exact costs, but rather represent relative orders of magnitude of cost differences between various transit options. A sample of such costs is shown in Table 5.

Table 5. Sample Functional Network Modal Costs

Mode	General Area	Fixed Cost per Round Trip	Variable cost per mile	Total Cost per roundtrip-mile
SPSS	Colombia to CENTAM	$1 million	Included in fixed	$1000
GFB (Long)	Colombia to CENTAM; EPAC Vector	$60,000 (crew + LSV)	$1.19	$25
GFB (Short)	Colombia to CENTAM; WCARIB Vector	$50,000 (crew)	$0.73	$37
Plane (Twin)	Colombia to CENTAM	$100,000 (aircrew)	$1.50–1.55	$45–55
Plane (Twin)	CENTAM	$50,000 (aircrew)	$1.55	$66
Truck	CENTAM	None	$0.70	$0.70
Truck	Smuggle across U.S.-Mexico Border	$5,000 (driver)	$0.65	$11.32

Shown are a sample of costs used in this model. Each mode has a fixed cost per round trip, which usually consists of a special crew pay. This amount varies by mode and location, but is generally higher for high-risk missions and if there is a special skill required (such as piloting an aircraft). In the case of the SPSS, the fixed cost is the cost of construction and operation since it is a single-use asset. In the case of the truck in Central America, there is no shortage of drivers and the risk of interception by authorities is low, hence the extra pay is zero. Crossing the U.S.-Mexico border, however, involves increased risk, so an extra bonus is used. Each mode also has a variable cost per mile, which consists of fuel and maintenance costs, as well as amortization of acquisition costs. Also shown for comparison purposes only is the total cost per round trip mile. Complete mode and SFNet arc-specific costs are provided in Appendix A.

2. Social Network Resource Data and Assumptions

Now that we have informed estimates for the total cocaine production and recent historical conveyance patterns, we can make certain transport assumptions to derive steady-state resource allocations for our notional DTOs. First, we need to assign each DTO a role and a mindset as in Table 2 in Chapter I (reproduced here as Table 6). These roles help inform where in the FNet a given DTO operates and can also provide guidance on relative resources a DTO possesses (e.g., a Mexican cartel DTO generally has more resources than an intermediate-level DTO). The mindsets help inform the asset mix for a given DTO, while also influencing where in the FNet a given DTO prefers to assign its resources.

Table 6. DTO Roles and Mindsets (Replication of Table 2)

DTO	Role(s)	Mindset
A	Source Transit	Primary focus on transport via the EPAC vector.
B	Source Transit	Primary focus on transport via the WCARIB vector, with lesser focus on the EPAC vector. Uses some aircraft.
C	Intermediate Transit	Primary focus on transit through Central America and Mexico via a mix of ground-based and airborne modes.
D	Intermediate Transit, Money Laundering	Ships exclusively via aircraft.
E	Cartel Leadership	Vertically integrated; most active cartel DTO along entire trafficking pipeline.
F	Intermediate Transit	Owns air cargo company and trucking company.
G	Cartel Leadership	Highly security conscious and prefers to operate behind-the-scenes with minimal overt activity. High U.S. political desire to interdict this DTO.
H	Cartel Leadership	Primary focus on importation. Significant use of cross-border tunnels from Mexico to US.
I	Intermediate Transit	Ships exclusively via its own trucking company.

A DTO's role is an indicator of its association to the FNet geography and of its resourcing level relative to other DTOs, while a DTO's mindset is an indicator of how it prefers to operate. As an example, a Source Transit DTO generally operates close to Colombia, while the mindsets shown indicate in which vector a given Source Zone DTO will usually operate. Some DTOs are strictly surface-based (DTO-A and DTO-I), while others have a mix of air and surface assets (DTO-F). These distinctions help guide the development of the resource allocations in Table 8.

In order for the DTOSFNI model to incorporate these DTO mindsets, we use a set of DTO behavior parameters to obtain results that affect the willingness of a particular DTO to apply resources to a particular functional node. This willingness is captured as a behavior parameter and is developed using the iterative maximum flow approach previously described (Table 7). For instance, DTO-A is able to apply truck resources to both the EPAC and WCARIB supply routes in Colombia, but according to Table 6, it is more preferable for it to operate in the EPAC as it generates more net profit potential for that DTO due to follow-on supply chain control. In Table 7, this behavior is obtained by making it 30% more costly for DTO-A to apply truck resources to the WCARIB vector. This also allows DTO-A to use the WCARIB routes if absolutely necessary (e.g., if DTO-B is interdicted).

Table 7. DTO Behavior Parameters

Parameter	Value	Description/Rationale
s_A_truck	1.3	Cost multiplier for DTO-A to use trucks for Caribbean transit due to preference for Pacific vector.
s_B_truck	1.1	Cost multiplier for DTO-B to use trucks for Pacific transit due to preference for Caribbean vector.
s_B_gfb	1.1	Cost multiplier for DTO-B to use GFBs in the Pacific vector due to preference for Caribbean vector.
s_G_ground	1.5	Cost multiplier for DTO-G to directly support functional flow due to preference for security and reduced exposure.
s_G_air	1.25	Cost multiplier for DTO-G to directly support functional flow due to preference for security and reduced exposure.

All listed parameters are used only for data preprocessing and are not part of the actual model formulation. Without these parameters, the arc-specific cost would apply equally to all DTOs and may cause certain undesired model behavior (such as DTO-G always acting overtly). Extending the DTO-G example, we want the cost for it to directly resource the FNet to be so expensive that it prefers to supply other DTOs first via SNet transfers, and only becomes directly involved when it is not feasible to do otherwise. The use of a cost-based penalty is an appropriate mechanism for controlling DTO behavior in the model as it allows the model to react dynamically, as opposed to using fixed constraints, which may be more cumbersome to employ and may only elicit the desired behavior across a limited set of circumstances.

Since the actual number of vehicles or assets utilized by a particular DTO is not available via open source channels, we again start with the known and make some assumptions about the unknown. We know the amount of cocaine that needs to be moved and we know its starting locations. By using our mindset assumptions (as well as assumptions about which DTOs are active in which FNet tasks) we can systematically and iteratively move the complete cocaine supply of 53t closer to the U.S. homeland, beginning in South America, and transiting Central America and Mexico. We describe one particular example of this iterative process in the following paragraphs.

For instance, there are two main DTOs (A and B) that move cocaine out of South America by GFB and/or SPSS. Since only a small amount of cocaine leaves Colombia via airplane (roughly 10% per Figure 1 in Chapter I), it is safe to assume that the remainder must be moved to the Colombian coastline from the cultivation and production sources. We assume that all intra-Colombian transport occurs via commercial-type trucks. Using assumptions for speed (25 miles per hour), distance to travel (175-250 miles), on-load and off-load times (two hours each), and return time, we can derive the

total time for a single roundtrip along a given functional arc. Depending on assumptions regarding truck turnaround or idle time (for maintenance or driver rest, etc.), in this instance a roundtrip would take about 24-48 hours. Using this approach we derive that one truck can make a maximum of 15-30 roundtrips per month. This assumes a continuous operation, however, which may be detrimental to maintaining secrecy and risks alerting the authorities. Therefore, a judgment call limits the number of allowable roundtrips per truck in Colombia to six.

Using capacity estimates derived using the capacity function described in Chapter III, we can now make an estimate of the number of trucks needed to move the entire ground-based supply of cocaine within Colombia and allocate them to DTO-A and -B according to what we assume to be their existent follow-on capacity. DTO-A focuses on the Pacific source and utilizes SPSS, while DTO-B focuses on the Caribbean source and relies more heavily on smaller GFBs. Hence, DTO-A has a greater demand for throughput from the source zones and ability to move more cocaine using maritime means, so we make a judgment call to allocate more trucks to DTO-A than to DTO-B.

In most cases, we tested the initial resource estimates by running the maximum flow model to ensure that all cocaine was moved into a given node "zone." Then the model was run to obtain resource estimates for the *subsequent* zone, which may or may not affect the resources required in the previous zone. As more zones received the total supply, the resource requirements were assessed to ensure they remained plausible and within the assumed mix of transport modes. Once the complete supply reached the destination (sink) node the maximum flow model was used to assess reductions in resources to "break" the models ability to move the entire source supply to the sink. The intent was to come up with a relatively lean steady-state trafficking instance in which there were few, if any, slack (e.g., reserve) resources.

The result of this iterative derivation process is shown in Table 8. With the exception of some aircraft, the only slack in resources exists with DTO-G, the low-key, behind-the-scenes entity.

Table 8. Social Network Steady-State Resource Supply Data

DTO	Auto	Truck	Plane (Twin)	Plane (Sngl)	Plane (UL)	SPSS	GFB (Long)	GFB (Short)	Tunnel
A		8		1		1	8		
B		4	2	(1)			1	4	
C	10		6	0	3				
D			6	2					
E		30	1	0		1	2	2	
F		20	3 (1)	(2)		1			
G	(20)	(20)	(5)	(5)	(3)				1+1
H	10	26	0	0	1				3
I		25							

Cell values indicate steady-state (non-interdicted) resource supplies at each DTO node. Values in parentheses indicate reserve (unused) supply at a given DTO node. Zeros indicate that a given DTO could apply a given resource to the functional model if a resource transfer occurs. Blank cells indicate that a given DTO cannot apply a particular resource, even if a transfer occurs. DTO-G has a single tunnel in steady-state, but may assume control of one of the DTO-H tunnels if the latter is interdicted. This tunnel is represented by the *s_G_tunnel* parameter in our DTOSFNI GAMS code.

As discussed in Chapter I, the DTOs in the SNet are able to transfer resources to each other and that a trust coefficient determines SNet arc capacities for resources that can physically or logistically be transferred between DTOs (Table 8). In the steady-state, non-interdicted base case, no transfer occurs. This models the assumption that each DTO has the resources immediately at hand in order to move all the cocaine supply it receives. Certain coefficients are relatively high (≥0.8), especially for the money-laundering DTO-D, and between the core Mexican cartel triad (E, G, and H). The values provided by Table 9, while arbitrary, represent a simple mechanism for modeling physical cooperation or even distrust between DTOs.

Table 9. Matrix of Social Network Trust Coefficients

Arc Trust		To Social DTO Node								
		A	***B***	***C***	***D***	***E***	***F***	***G***	***H***	***I***
From Social DTO Node	***A***	1	0	0.7	0.9	0	0.6	0	0	0
	B	0	1	0.7	0.9	0	0.7	0	0	0
	C	0.6	0.6	1	0.9	0.6	0	1	0.6	0
	D	0.8	0.8	0.8	1	0.9	0.8	0.9	0.9	0.8
	E	0	0	0.7	0.9	1	0.6	0.8	0.7	0.8
	F	0.5	0.5	0	0.9	0.6	1	0.7	0.6	0
	G	0	0	0.7	0.9	0.8	0.5	1	0.8	0.5
	H	0	0	0.7	0.9	0.7	0.5	0.8	1	0
	I	0	0	0	0.9	0.9	0	0.7	0	1

These trust coefficients determine the willingness of one DTO to transfer or share resources with another DTO if the enterprise is attacked and are not required to be symmetrical. Due to personalities or prior experiences, one DTO may actually trust another DTO more so than in the reverse case. One such example is the A→D/D→A relationship in which DTO-A trusts DTO-D (coefficient of 0.9) more so than DTO-D trusts DTO-A (coefficient of 0.8).

3. Social-Functional Network Data and Assumptions

The remaining data and assumptions describe the connection of the SNet to the FNet. Table 10 is a list of resource-specific FNet arcs that connect geographic sub-nodes for each FNet node.

Table 10. Functional Network Arc List

FNet Arc ID	FNet Node	From	To	Mode
1_1	Colombia Transit (Pac)	SA_Source_Pac	SA_Coast_Pac	Truck
1_2	Trans-Colombia Transit	SA_Source_Carib	SA_Coast_Pac	Plane_Sngl
2_1	Colombia Transit (Carib)	SA_Source_Carib	SA_Coast_Carib	Truck
2_2	Trans-Colombia Transit	SA_Source_Pac	SA_Coast_Carib	Plane_Sngl
3_1	Direct Air Transit	SA_Source_Pac	CA_Trans	Plane_Twin
3_2		SA_Source_Carib	CA_Trans	Plane_Twin
3_3	Pac GFB Transit	SA_Coast_Pac	CA_Trans	GFB_Long
3_4	Pac SPSS Transit	SA_Coast_Pac	CA_Trans	SPSS
3_5	Carib GFB Transit	SA_Coast_Carib	CA_Trans	GFB_Short
4_1	CENTAM Transit	CA_Trans	Mex_Trans	Truck
4_2		CA_Trans	Mex_Trans	Plane_Sngl
4_3		CA_Trans	Mex_Trans	Plane_Twin
5_1	Mexico Transit	Mex_Trans	Mex_Border	Truck
5_2		Mex_Trans	Mex_Border	Plane_Sngl
5_3		Mex_Trans	Mex_Border	Plane_Twin
6_1	Import Tunnel	Mex_Border	US_Border	Tunnel
7_1	Import Air	Mex_Border	US_Border_UL	Plane_UL
8_1	Import Ground, Transit to Sink	Mex_Border	US_Sink_Phoenix	Truck
8_2		Mex_Border	US_Sink_Phoenix	Auto
8_3	Import Air	Mex_Border	US_Sink_Phoenix	Plane_Sngl
8_4		Mex_Border	US_Sink_Phoenix	Plane_Twin
8_5	Transit to Sink	US_Border	US_Sink_Phoenix	Truck
8_6		US_Border	US_Sink_Phoenix	Auto
8_7		US_Border_UL	US_Sink_Phoenix	Truck
8_8		US_Border_UL	US_Sink_Phoenix	Auto

These FNet arc IDs are used as short aliases for the long FROM-TO names in the FNet split-nodes. The FNet arcs are generally grouped by the location to which cocaine is being supplied. The first digit in the FNet arc ID indicates this grouping, while the second digit in the ID is used to distinguish the applicable mode of transport. This prevents impermissible assignments, such as using a GFB on a land-based transport function.

The connections, or arcs, from the SNet nodes to the FNet arcs are represented by a matrix of binary values (Table 11). Note that while a connection may exist from a DTO to a resource-specific FNet arc, this does not imply that the DTO has sufficient resources to apply to that arc. It only indicates an ability to apply available resources.

Table 11. Social Network to Functional Network Arc Matrix

	FNet Arc ID																								
DTO	**1_1**	**1_2**	**2_1**	**2_2**	**3_1**	**3_2**	**3_3**	**3_4**	**3_5**	**4_1**	**4_2**	**4_3**	**5_1**	**5_2**	**5_3**	**6_1**	**7_1**	**8_1**	**8_2**	**8_3**	**8_4**	**8_5**	**8_6**	**8_7**	**8_8**
A	1	1	1	1			1	1	1																
B	1	1	1	1		1	1		1																
C												1			1		1		1	1	1		1		1
D					1	1					1	1		1	1										
E							1	1	1	1	1	1	1	1	1			1	1						
F					1	1		1		1	1	1	1	1	1			1		1	1				
G										1			1			1		1	1			1	1		
H													1			1	1	1	1	1		1	1	1	1
I													1	1	1		1	1		1					

A value of 1 indicates that a given DTO can apply a particular resource to the given resource-specific FNet arc. Blank cells indicate that a given DTO has no ability to apply a resource to the given FNet arc.

B. MODEL RESULTS AND ANALYSES

The enumerated results of the DTOSFNI model runs are presented in this section. We are interested primarily in the percent reduction in the objective value (monthly "profit" in USD) from the base case, with a secondary goal of drawing DTO-G into the open in order to increase evidence-gathering opportunities against it. The first three sub-sections are divided according to the number of interdicted SNet nodes used in the attack plan and discuss results with respect to the primary goal. The fourth sub-section discusses results with respect to the secondary goal, which also provides some insight into why the primary goal results appear as they do. Highlights of the results are shown in this section; complete results are available in Appendix B.

1. Analysis of One-DTO Attack Plans

This section considers the case when one DTO is interdicted or removed from the SFNet. There are nine DTOs in our social network, and so there are nine possible attack plans plus the base un-interdicted case. The base case yields a trafficker "profit" of $5,289.65 million. The enumerated attack results are shown in Figure 13 as a percentage reduction from the base case trafficker profit.

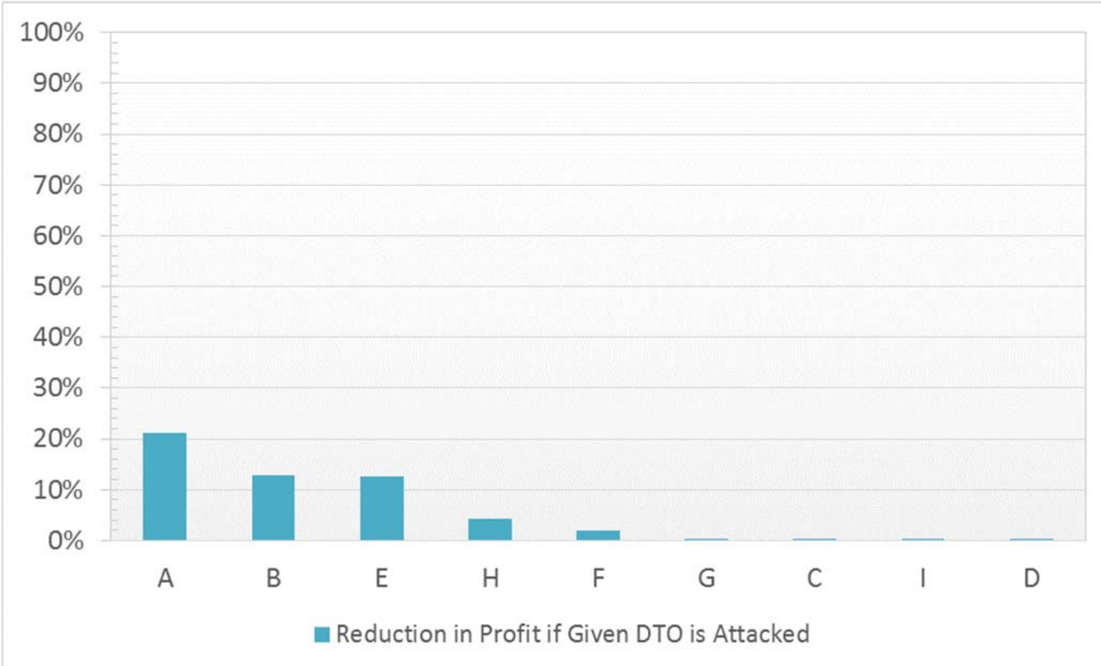

Figure 13. One-DTO Attack Plan Results

The results clearly show that interdicting either of the two source zone DTOs (A or B) or the highly involved cartel leader (E) yields the most favorable results with respect to the primary goal of reducing trafficker profit. Attacking DTO-A achieves the greatest reduction in profit, while attacking DTO-B or -E yields a clear second tier of attack options. An attack on DTO-H allows the traffickers to gain rewards on most of the cocaine flow until just short of the U.S. border. Surprisingly, an attack on DTO-F is not very lucrative, even though this removes one SPSS from the resource supply. Attacking DTO-G has little effect, though this is expected since it is not active in the system in the non-interdicted case. Of note, DTO-C, -I, and -D are smaller organizations that focus on only one or two modes of transportation. This focused characteristic may indicate that any loss of their resources may be easily offset by the multi-modal capacities of the other DTOs.

It is clear that attacking DTO-A provides the largest reduction in trafficking profit by a significant margin, which is expected due to its high throughput from the source zone. Attacking DTOs B or E provides lower, similar reductions, while attacking H or F yields correspondingly lower reductions. Each of these five attack plans achieves profit reduction primarily through limiting the flow of cocaine itself. There is also a compounding effect of cutting off flow earlier in the supply chain as later rewards are not gained. Attacking DTOs A, B, or E prevent a large amount cocaine from even reaching Central America, as does attacking DTO-F to a much smaller extent. Attacking DTO-H achieves all of its reduction at the U.S. border through the net removal of two tunnels.

Attacking any of the remaining DTOs (C, D, I, and G) yields very little reduction in trafficking profit, most which is achieved by shifting the cocaine flow to more costly modes and/or routes, rather than by reducing it altogether.

2. Analysis of Two-DTO Attack Plans

This section considers the case when two DTOs are simultaneously (or near-simultaneously) interdicted or removed from the SFNet. The results for the dual attacks that provide marginal improvement over the individual attacks on either sub-component are shown (along with the single attacks for comparison purposes) in Figure 14.

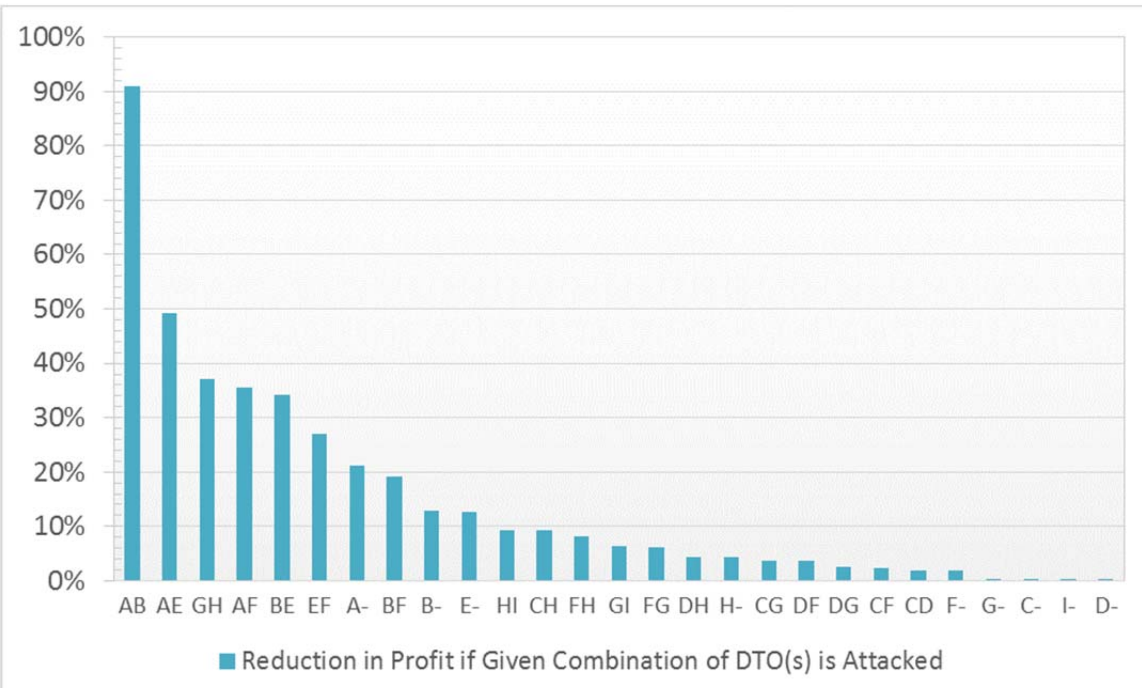

Figure 14. Combined One-DTO and Marginally Effective Two-DTO Attack Plan Results

Only dual attack plans that provide marginal benefit over single attacks on its sub-components are shown here. The AB attack plan yields the greatest reduction in profit, primarily due to the fact that Colombia production sources are almost completely isolated from the rest of the supply chain by the lack of any truck assets to move cocaine from production areas to the Colombian coastline. An AE combination yields the second best results and can decrease cocaine profits by almost 50%. Especially noteworthy is the fact that several dual attack plans are no more beneficial than the top three single attack plans (A, B, or E). While combinations of attacks on DTO-A, DTO-B, or DTO-E present in the top six results are not unexpected given the single attack results, what is interesting is the GH attack that ranks third.

It is clear from these results that the best attack options all include some combination of A, B, E, or F (two source zone DTOs, a cartel-level DTO, and an intermediate DTO), the last of which was not obvious from the single attack plan results. Geography of our network can help explain some of these outcomes as the restriction of cocaine flow occurs early in the supply chain. The AB attack essentially isolates the cultivation and production zones in Colombia from the maritime routes, leaving only risky, expensive air routes available to the surviving DTOs. Such an attack may be infeasible in the real world as there are numerous Colombian and maritime-based DTOs and it would be difficult to take most or all of them down. However, pairing a source zone DTO with a vertically-integrated DTO (such as E or F) that operates in the maritime region between Colombia and CENTAM and further moves cocaine through CENTAM and Mexico appears to yield good results. Of these types of attack plans, the AE attack performs the best, followed by AF, as each removes 2/3 of the SPSSs from the base case.

While these results imply that each of the better dual attack plans will include at least one of the better single attack plans, there is no guarantee that this will be the case. The results also show that simply attacking any two DTOs is also not guaranteed to be any better than attacking a single DTO (see Table 12). The 3rd-best ranking of the GH attack in Figure 14 indicates that other variables may have a synergistic effect (in this case such an attack removes all tunnels as a resource) and that attacks on two previously inconsequential DTOs may have an outsized effect if combined. Another important observation is that, other than the GH attack, attacking two Mexican cartel-level DTOs provided no better results than attacking DTO-E alone.

Table 12. Marginally Ineffective Two-DTO Attack Plans

AC	AH	BD	BI	DE	EG
AD	AI	BG	CE	DI	EI
AG	BC	BH	CI	EH	FI

These attack plans provide either fractional (<0.1%) or no additional benefit over a single attack on one of its components. In most cases, the beneficial single attack is A, B, or E. Plans C, D, and I proved unfruitful in the single attack results and provide no added value when combined with A, B, or E. It is noteworthy to see that the EG and the EH attacks have no benefit over a single E attack although each comprise 2/3 of the Mexican cartel leadership triad.

3. Analysis of Three-DTO Attack Plans

This section considers the case when three DTOs are interdicted or removed from the SFNet. While we actually enumerate all 84 triple attack plans in the full results shown in Appendix B, we first focus on adding a third attack to each of the top seven dual attacks to observe any nested results, and then consider additional attack options. All marginally effective triple attack options that yield greater profit reductions than a single E attack are shown in Figure 15.

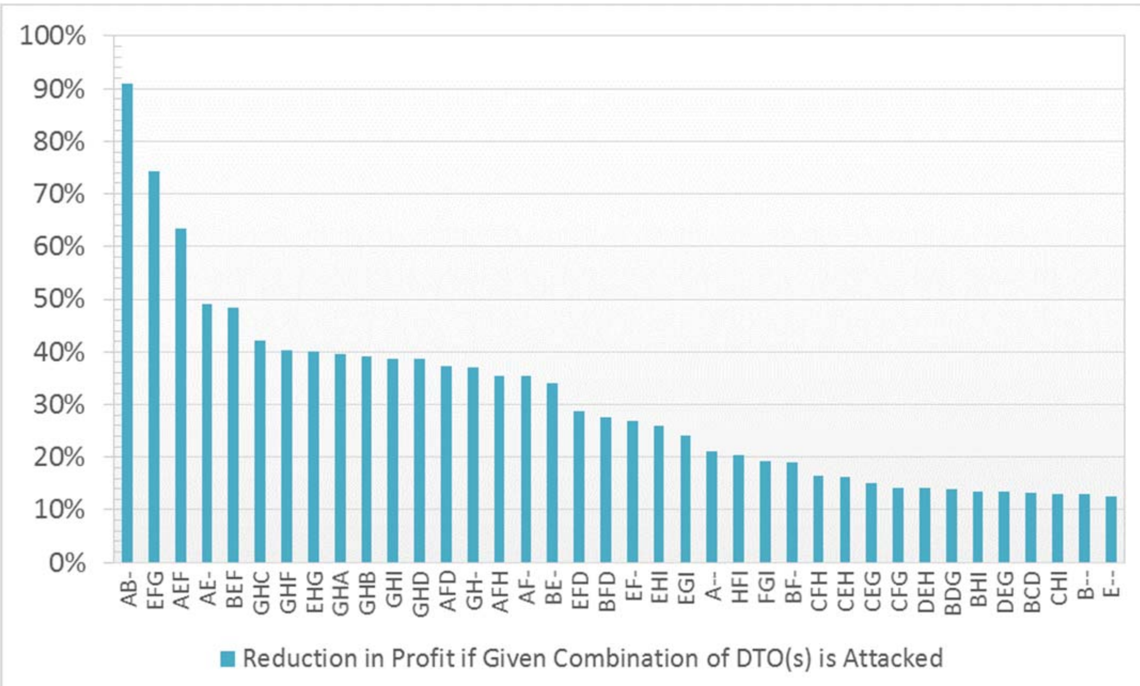

Figure 15. Combined One-DTO and Marginally Effective Two-DTO and Three-DTO Attack Plan Results

Only triple attacks that provide a marginal benefit over the maximum underlying single attack or dual attack component, and perform better than a single attack on DTO-E, are shown here. Note that the AB attack plan still yields the greatest reduction in profit, and any third attack that extends this dual attack will provide zero added benefit. Rather than exploiting one of the expected DTOs from the single attacks (A, B, or E), the surprisingly well-performing dual GH attack is most improved upon by attacking the previously inconsequential DTO-C.

As with the Two-DTO attacks, there are several Three-DTO attack plans that do not perform as well as the better single or dual attack plans. This is further evidence that

simply adding attacks indiscriminately does not guarantee better results than attack plans with fewer interdicted DTOs.

Just as the Two-DTO attack plans produced a surprising 3rd-best result for a GH attack, the Three-DTO attack results begin to show interesting interactions (or lack thereof) as more of the network is interdicted. It is clear that no third attack option can improve upon the dual AB attack. If we omit that option, however, we observe that the previously 6th-best dual attack (EF) provides a better basis upon which to build third attack options than AE (2nd-best), GH (3rd-best), AF (4th-best), and BE (5th-best). We also see previously inconsequential DTOs becoming keys to attacking the trafficking network. For instance, note that the new 2nd-best overall attack plan combines EF with G, a point which is explored further in the next section. Also, the best augmentation to a dual GH attack is not to attack one of the "usual suspects" (A, B, or E), but rather to include DTO-C instead.

While no third attack can improve upon the dual AB attack plan, we observe two triple attack options that exceed a 60% reduction: EFG and AEF. The EFG attack plan effectively cuts out 2/3 of the base case SPSSs while preventing reserve resources from being applied. The AEF attack plan cuts out all SPSSs from the network, but this is partially offset by the availability of DTO-G reserves. These two attacks plans are also the only Three-DTO attack plans that dominate any Two-DTO attack plan, with the exception of AB.

Also noteworthy is that attacking all three Mexican Cartel DTOs (EGH) provides only middling results. That may indicate that the enterprise can likely survive the simultaneous loss of all three, and perhaps afford one or more of the remaining DTOs an opportunity to "promote" and fill this void.

4. When Evidence-Gathering Against DTO-G is Desired

We may also use our DTOSFNI results to evaluate how a particular attack plan forces the surreptitious DTO-G to become more active in the network under the hypothesis that this will lead to increase evidence-gathering opportunities for law enforcement. (Note that this same approach can be used to select attack plans to *avoid*

causing a DTO to become more active.) For this example, while any range of metrics that consider SNet resource transfers or capacity added to the functional network are valid, our metric is a relatively simple summation of all assets that DTO-G must apply directly to the functional network under a given attack plan scenario. Scatterplots of the primary objective (profit reduction explicit in the DTOSFNI model) versus this secondary objective (increased activity as a consequential output from the model) may actually help explain some of the unexpected results shown in the previous sections. First we consider the One-DTO interdiction results (Figure 16).

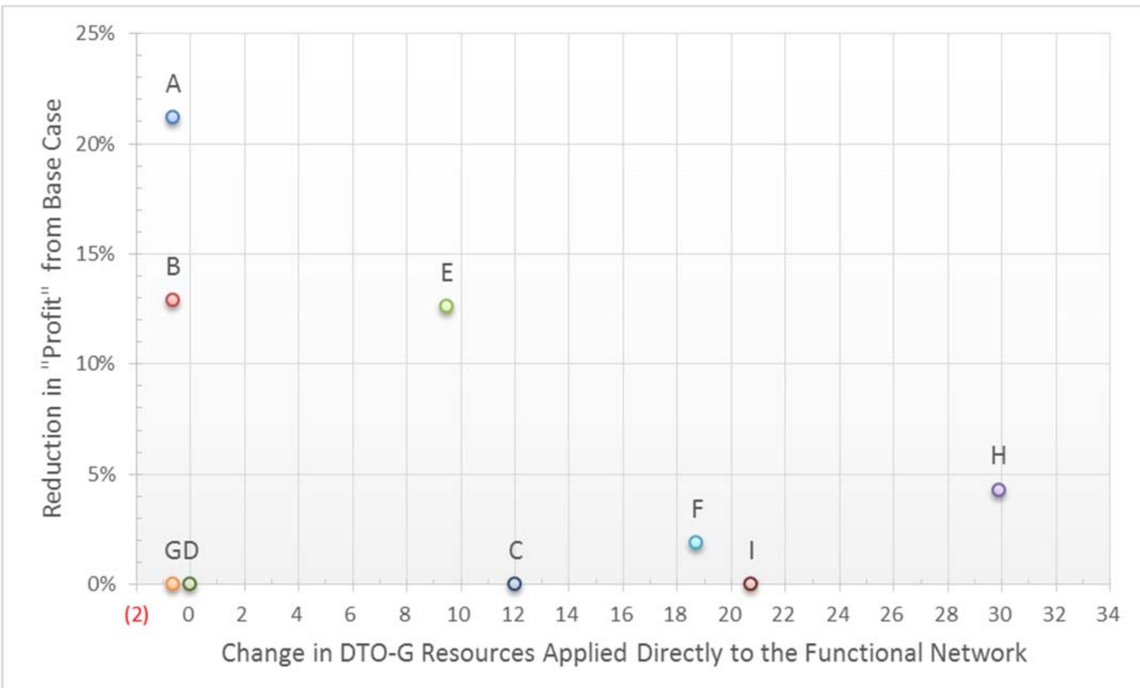

Figure 16. Evidence-Gathering Results for One-DTO Attack Plans

These results clearly show that interdicting either of the two source zone DTOs (A or B) or the highly involved cartel leader (E) yields the most favorable results with respect to the primary goal of reducing profit. Attack plans that focus on the secondary goal of forcing DTO-G to become more overt yield little to no reduction in trafficking profit, with the H attack plan forcing DTO-G to be the most active.

The goal of minimizing the traffickers' profit initially appears to be at odds with an evidence-gathering strategy. If we can execute a single attack, and no more, then we would attack the highest yielding DTO in terms of profit reduction and be done with it.

Analyzing corollary results, however, is extremely useful in attempting to determine how a trafficking network may react to a given attack, and can help law enforcement *anticipate* the adversary's response. The key here is that even if the model returns a response that ultimately does not come to fruition, this fact actually tells us something that we did not previously know about the traffickers' network, whether it be that a previously unobserved actor is now active (similar to an unobserved DTO-G, for instance) or that the DTOs have a different set of resources available to them. This approach can also be useful when determining how to stimulate the network in order for the traffickers to reveal themselves or make a more exploitable mistake. "Priority" targets for a particular type of attack plan (i.e., a single attack) may not actually be priority targets for a given dual attack plan, as shown in Figure 17.

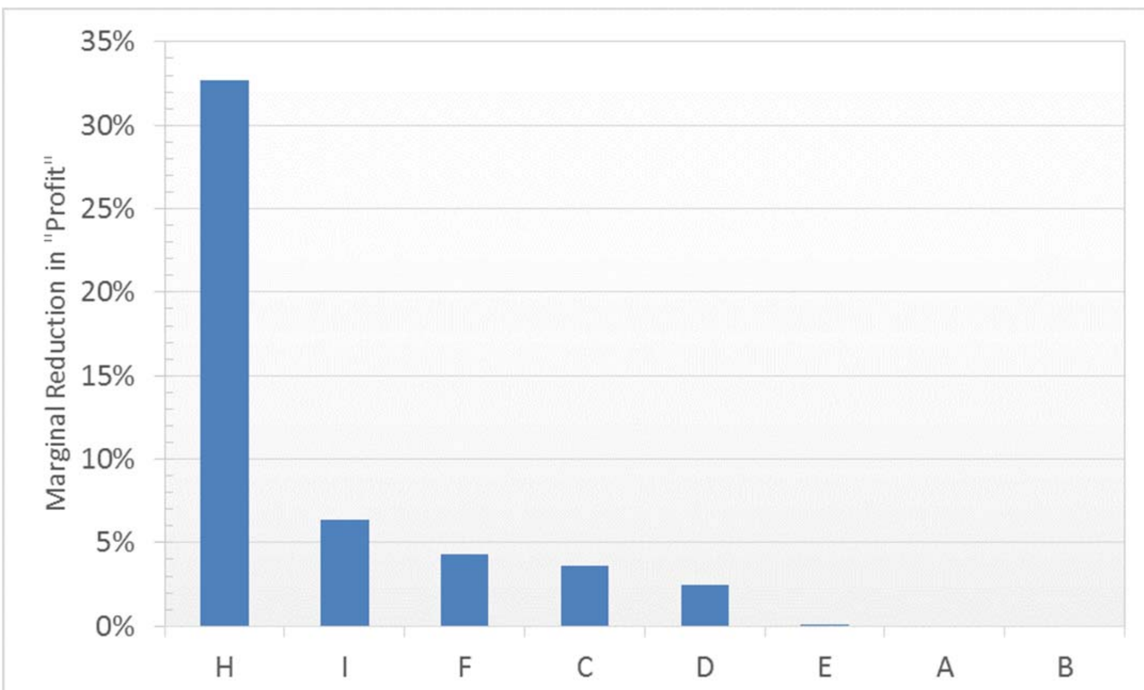

Figure 17. Marginal Improvement when DTO-G Added as Second Attack

The marginal improvement over a given single attack plan when DTO-G is added as a second attack is shown here. As indicated by Figure 14, the H attack plan yields the most DTO-G activity. Subsequently attacking DTO-G in addition to the original DTO-H attack yields an extra 32.7% reduction in trafficker profit. The A and B attack plans reduce the need for DTO-G activity, so it is to be expected that DTO-G provides no better when added to either single attack. The only surprising results are the increase gained when augmenting a single D attack (0 increase in DTO-G activity), and the lack of benefit when augmenting a single E attack.

Next, we consider how Two-DTO attack plans affect DTO-G activity and how this may affect our Three-DTO attack decisions (Figure 18).

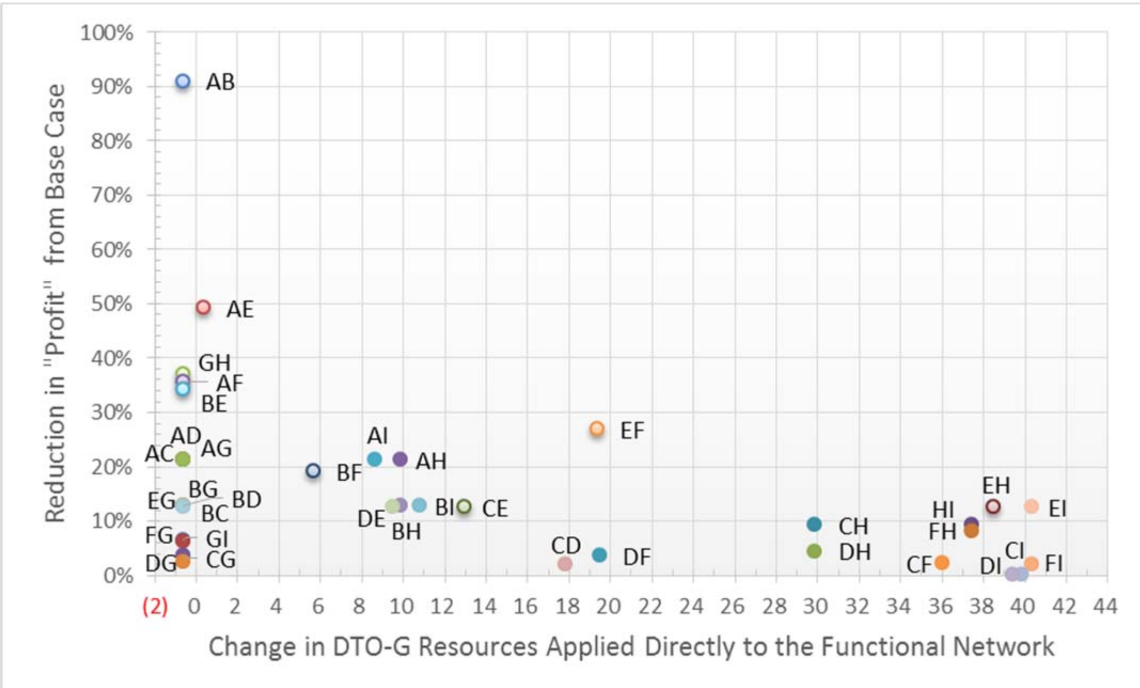

Figure 18. Evidence-Gathering Results for Two-DTO Attack Plans

This plot looks very similar to that in Figure 16. The upper left dual AB attack builds from the single A attack, while the dual EF attack improves upon the single E attack. Dual attack based on the single H attack are generally found in the lower-right of the plot. This lower-right portion of the graph also has a few I-based attacks and a CF attack. This leads us to consider EF and the group of dual attacks in the lower-right as potential candidates for more lucrative triple attacks adding DTO-G.

We can observe from Figure 18 a few items of interest. First, one could determine there are roughly five major clusters of results:

1. those that *reduce* or effect little change in DTO-G activity and have a wide range in profit reduction,
2. those that increase DTO-G activity slightly (6-13 assets), with a low level of profit reduction,
3. those that increase DTO-G activity a moderate amount (18-20 assets) but have almost no profit reduction,
4. the EF result that shows a moderate DTO-G activity increase, but has significant profit reduction as well, and

5. those that maximize DTO-G activity (30-41 assets), but have little reduction in profit (less than 15%).

Second, we can use this information to narrow our candidate list of triple attacks to evaluate if computational run time is of concern (say for real-world applications with networks that are much more detailed and complex). While we do enumerate all 84 triple attack plans, we present our results here in terms of attack plan EF and those in the fifth cluster. We also include results for attack plans AB, AE, BH, and AH in order to show how select "non-sampled" results rank (Figure 19).

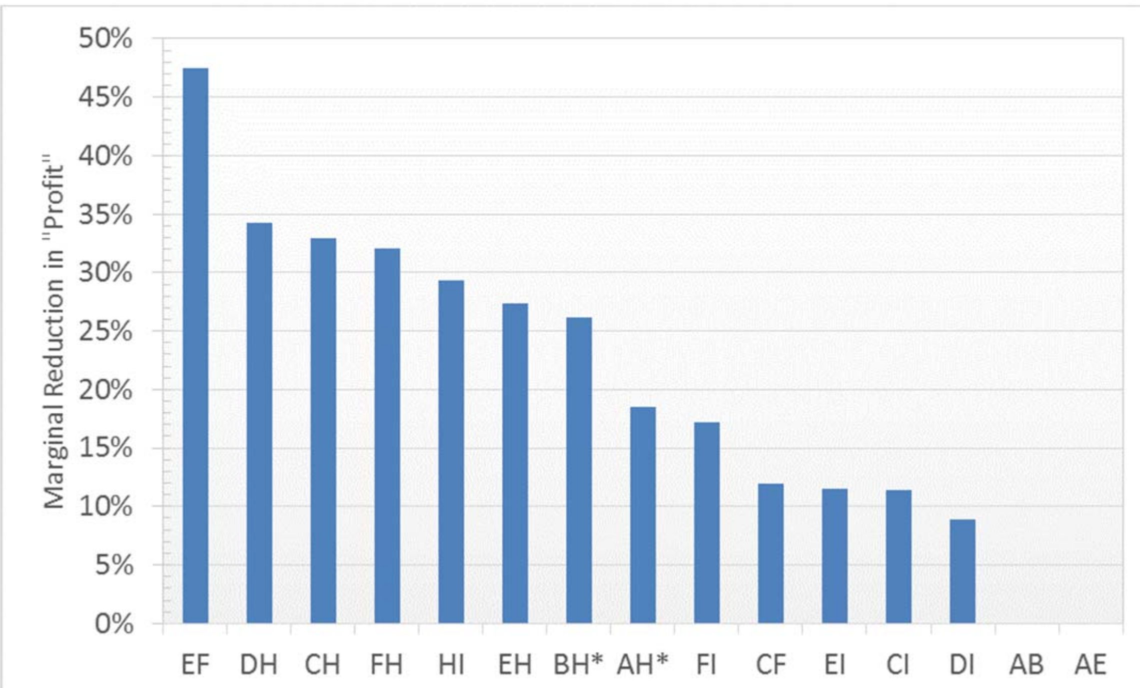

Figure 19. Marginal Improvement when DTO-G Added as Third Attack

The marginal improvement over a given dual attack plan (selected from the clusters in Figure 18) when DTO-G is added as a third attack is shown here. Attack plans marked with an asterisk do provide significant marginal benefit, but would not have been selected for further evaluation if the cluster prioritization approach were to have been used. Unlike the relatively predictable results in Figure 17, using the scatterplot approach in this instance is not as predictive in determining potential lucrative attack combinations. While every attack plan in the fifth cluster does lead to further reductions if DTO-G were to also be attacked, there does not appear to be a clear hierarchy that may be discerned (e.g. more DTO-G asset exposure leads to greater benefit if DTO-G is subsequently attacked). The group of attacks that include DTO-H appears to correspond to the GH_ group of attacks in Figure 15. The clear outperformance of the EF attack plan, which has only a moderate impact on DTO-G resource application, over the fifth cluster options indicates that there are other interactions or variables that come into play at the three-attack level.

5. Summary of Results and Analyses

Overall, DTOs -A and -E are the most lucrative targets in the SNet, followed closely by DTOs -B and -F. When multiple DTOs are attacked, certain combinations of DTOs that are inconsequential in scenarios with fewer attacks may exhibit a synergistic effect and provide surprisingly large relative reductions in trafficking profit. Other combinations provide no additional benefit or actually perform worse than plans with fewer attacks.

When only one attack is available, the top three attack plans—A, B, and E—all focus on DTOs that provide significant contributions to the task of moving cocaine from Colombia to Central America, primarily by maritime means. Reductions in profit for these three attack options range between 12.6–21.2%.

When two attacks are available, three of the top five performing attack plans include DTO-A, and four of the top five incorporate either or both of the source zone DTOs. The one outlier in the top 5 is a GH attack (3rd best) that provides us with the first evidence of potentially unforeseen synergistic attack effects. A single attack on DTO-E, however, dominates any other dual attack against two Mexican cartel-level DTOs. Reductions in profit for the top five dual attack options range between 34.1–91.0%.

The triple attack options yield some interesting results. The dual AB attack dominates every triple attack plan, and the 2nd-best dual AE attack dominates all but two triple attack plans, with the exceptions being EFG (74.4% profit reduction) and AEF (63.5%). As with the dual attack results, a triple attack plan focused on the Mexican cartel-level DTOs (the EGH attack) is dominated by at least seven other dual and triple attack plans.

So one of the primary questions the reader may ask is, "Why not simply consider only the dual AB attack?" The primary reason is that it may not be practical or feasible to remove every source zone DTO in the real world. The collapse of the major Colombian cartels in the late-1990s and early-2000s led to a complete fracturing of the drug trade emanating from this region. A dual AB attack for the model would be akin to removing perhaps a dozen real-world minor DTOs that might easily reconstitute or shift unmet

trafficking demand to surviving DTOs relatively easily. While this is not explicitly modeled for this thesis, the enumeration of attacks allows us quickly see the effect of constraining our attack options.

For instance, if we were to constrain our choices to attacking no more than one source zone DTO, the best dual attack option is AE (49.2%), while the only triple attack options that would be more beneficial are EFG and AEF. Likewise, if it is deemed infeasible to attack more than one Mexican cartel-level DTO, the remaining triple attack option is AEF. Note that in each of these cases (AE, EFG, and AEF), at least 2/3 of the SPSS resources are no longer available. This suggests that while GFBs may account for more trafficking events, and perhaps a majority of tonnage moved, the SPSS remains a high payoff resource for the traffickers, and a potential vulnerability to exploit—not by traditional interdiction-at-sea, but by preventing their construction and use in the first place by interdicting the social network financiers and managers.

We may also use secondary information provided by the DTOSFNI model to evaluate evidence-gathering prospects or to observe potential responses by remaining DTOs under a given attack plan.

V. RECOMMENDATIONS AND CONCLUSIONS

The value of a model comes from the unforeseen insights it provides the decision maker. The drug trafficking problem is certainly a very complex and extensive one—so much so that there is no guarantee of obtaining optimum attack results by simply "eyeballing" the problem using experience and instinct. It is clear that DTOs are not alike and cannot be targeted haphazardly; even intuition-based grouping or categorization of DTOs is insufficient in determining the best entities to target. However, we have shown that a comprehensive, methodical, and analytical approach, such as the one used to develop the DTOSFNI model, can help elicit otherwise unforeseen insights and be useful for informing the development of counterdrug strategy and/or policy.

As cocaine can only be produced in a very limited area of the world, it is not surprising that eliminating almost all primary means for cocaine to leave this area (the AB attack) would yield the best results in our hypothetical situation. No one needs a model such as DTOSFNI to make this observation. Where the DTOSFNI model is useful is in addressing, "What else?" if such an attack plan was not feasible.

It is also extremely useful when a problem exceeds the capability of "manual" alternatives. Our simplified hypothetical model only has nine nodes that can be interdicted, yet even this allows for 84 possible combinations of three-attack plans. Of these 84 possibilities, fewer than 5% are even worth considering. The chances of choosing one these superior plans by happenstance are extremely slim, as are the chances of learning that most of this performance can be attained with specific combinations that use only *two* attacks. Now expand the fidelity of the model to include just five "individuals" within each of the nine DTOs for a total of 45 nodes that can be interdicted. To attack just three of these 45 nodes, there are 14,190 possible options, most of which will actually prove to be unfruitful. To attack the equivalent of what we show in this thesis would require 15 attacks, or $3.4*10^{11}$ combinations. What would be impossible to analyze manually (or qualitatively), quantitative analytical methods makes possible.

Even with such an expanded problem, there is value in simply going through the process of putting the data into the DTOSFNI model. First, it requires the analyst to explicitly identify his or her assumptions (such as capacities, speed of advance, trust coefficients, etc.).

Second, archiving such assumptions in a common format should allow different parties in the "blue" network (such as the FBI, DEA, U.S. military and other intelligence agencies, etc.) the ability to share such knowledge and challenge disparate estimates more transparently. Ranges in these assumptions can easily be explored using further model excursions to determine which assumptions are robust (those in which relatively large deviations do not cause divergent results) and those against which more investigative effort must be applied in order to turn them into facts.

Third, increased sharing of structured information (policy restrictions notwithstanding) allows for the development of a true counterdrug Common Operational Picture (COP). One such manifestation of this COP could be a living diagram of the social and functional networks as described in this thesis. As DTOs come and go, the information in the COP could be updated by one party, vetted by a group, and quickly propagated as an informational update to the entire community.

Potential applications of the DTOSFNI and its supporting analytical process, therefore, include not just "simple" targeting prioritizations (to support CPOT development and investigation prioritization), but also identify knowledge gaps and policy obstacles to information sharing across the counterdrug community. Investigations appear to be very organization- or personality-driven, not only when considering the adversaries, but when considering the "blue" network as well. The FBI may be focused on one particular DTO, and the DEA on yet another, while DOD intelligence agencies are spread thin between one or more other DTOs. Each blue organization's target priorities may be slightly different from the others, and compartmented information and access often makes joint investigations difficult to execute. While there are fora, such as JIATF-S, where information-sharing ostensibly occurs, it is often limited to the least amount of sharing necessary to obtain a limited end for specific, compartmented cases files. Empowerment of information-sharing fora, beyond what has already been—and

continues to be—done at JIATF-S as an example, and using a comprehensive approach may provide the counterdrug community with a means for increased success against the cocaine traffickers.

The OCDETF CPOT list is another coordinating mechanism, and though the author is not privy to the prioritization schema used to develop the CPOT list, it is likely driven by political considerations, DTO activity levels, and perhaps DTO market "capitalization." It is unclear whether a comprehensive prioritization of investigative effort occurs, but the DTOSFNI model can be extremely useful in supporting such a comprehensive approach, especially as we have shown that political or intuition-based priorities may be focused on the wrong entities, at least as far as reducing the traffickers' profit, or cocaine flow, is concerned. Removing all the major Mexican cartels is not the answer, even if it were feasible. However, removing the right combinations of DTOs can achieve significantly greater reductions in profit, and the DTOSFNI model can help identify which combinations to pursue.

The DTOSFNI model can be used to anticipate DTO responses to attack, at least in terms of social resource transfers and direct applications to the functional network. While we focus on how attacks change the level of overt activity of a particular behind-the-scenes DTO, this same approach can be used to evaluate how any DTO may react to a network attack and law enforcement can set up evidence-gathering efforts accordingly. Direct applications of resources may be observed while resource transfers inevitably involve increased communication between previously less-connected DTOs, which may also be exploited. Evidence-gathering and actual interdiction activity can and should inform each other: they are not mutually exclusive goals.

In conclusion, we have demonstrated the value of combining traditional operations research and social analysis techniques into a hybrid model that considers both the social actors themselves and the goals they are attempting to achieve, in order to evaluate interdiction options to disrupt achievement of those goals. As in all studies of this nature, the DTOSFNI model and the structured methodology described herein may provide a foundation upon which to build more sophisticated models or approaches. Future work could include the use of real-world LES data, expansion of the DTO nodes

to include individual person nodes, modification of the DTOSFNI model to consider competing DTOs and/or cartels, and consideration of “balloon” effects (the idea that putting pressure on one set of drug routes or DTOs simply creates increased activity in a different region), among others.

APPENDIX A. ADDITIONAL DATA

Appendix A provides data that is either: a) not presented elsewhere in this thesis, or b) presented elsewhere but is provided in greater detail here. Geo-physical data specific to each FNet arc are shown in Table 13.

Table 13. Functional Network Mode-Specific Time-Distance Data

FNet Arc ID	From	To	Mode	Dist. (miles)	R/T Dist. (miles)	Speed (mph)	R/T Time (hrs)
1_1	SA_Source_Pac	SA_Coast_Pac	Truck	173	346	25	13.8
1_2	SA_Source_Carib	SA_Coast_Pac	Plane_Sngl	585	1,170	140	8.4
2_1	SA_Source_Carib	SA_Coast_Carib	Truck	232	464	25	18.6
2_2	SA_Source_Pac	SA_Coast_Carib	Plane_Sngl	630	1,260	140	9
3_1	SA_Source_Pac	CA_Trans	Plane_Twin	1,130	2,260	190	12
3_2	SA_Source_Carib	CA_Trans	Plane_Twin	950	1,900	200	9.6
3_3	SA_Coast_Pac	CA_Trans	GFB_Long	1,260	2,520	10	256
3_4	SA_Coast_Pac	CA_Trans	SPSS	1,000	1,000	8	250
3_5	SA_Coast_Carib	CA_Trans	GFB_Short	684	1,368	12	114
4_1	CA_Trans	Mex_Trans	Truck	574	1,148	25	46
4_2	CA_Trans	Mex_Trans	Plane_Sngl	386	772	140	5.6
4_3	CA_Trans	Mex_Trans	Plane_Twin	386	772	200	3.8
5_1	Mex_Trans	Mex_Border	Truck	2,067	4,134	35	118
5_2	Mex_Trans	Mex_Border	Plane_Sngl	1,544	3,088	140	26
5_3	Mex_Trans	Mex_Border	Plane_Twin	1,544	3,088	200	17.4
6_1	Mex_Border	US_Border	Tunnel	0.25	0.5	2	0.26
7_1	Mex_Border	US_Border_UL	Plane_UL	13	26	50	0.52
8_1	Mex_Border	US_Sink_Phoenix	Truck	234	468	50	9.4
8_2	Mex_Border	US_Sink_Phoenix	Auto	234	468	65	7.2
8_3	Mex_Border	US_Sink_Phoenix	Plane_Sngl	234	468	140	4
8_4	Mex_Border	US_Sink_Phoenix	Plane_Twin	234	468	200	3
8_5	US_Border	US_Sink_Phoenix	Truck	233	466	50	9.4
8_6	US_Border	US_Sink_Phoenix	Auto	233	466	65	7.2
8_7	US_Border_UL	US_Sink_Phoenix	Truck	224	448	50	9
8_8	US_Border_UL	US_Sink_Phoenix	Auto	224	448	65	7

All distances are converted to statute miles and all speeds are in miles per hour. All air routes are considered to be point-to-point direct, with the exception of 3_1 and 3_2 which take the shortest routes from the Colombian production areas to southern Honduras while also avoiding Nicaraguan airspace. The round trip times shown do not take into consideration on- or off-load times, maintenance periods or any reset delays.

Data used for the FNet arc capacity functions approximations are shown in Table 14.

Table 14. Functional Network Capacity Function Data

FNet Arc ID	Mode	R/T per Month	Tier 1 Break Point bp_1	Tier 1 Slope (t)	Tier 2 Break Point bp_2	Tier 2 Slope (t)	Tier 3 Break Point bp_3	Tier 3 Slope (t)
1_1	Truck	6	1	5.4	4	4.5	12	3.9
1_2	Plane_Sngl	2	1	0.5	2	0.4	4	0.3
2_1	Truck	6	1	5.4	2	4.5	8	3.9
2_2	Plane_Sngl	2	1	0.5	2	0.4	4	0.3
3_1	Plane_Twin	1	1	0.5	2	0.45	3	0
3_2	Plane_Twin	2	1	1.4	2	1.3	3	1.1
3_3	GFB_Long	2	3	2	6	1.6	12	1.2
3_4	SPSS	1	2	8	4	6	8	5
3_5	GFB_Short	3	2	3	4	2.4	8	1.8
4_1	Truck	4	4	4	8	3.2	15	2.4
4_2	Plane_Sngl	2	1	0.5	2	0.4	3	0.34
4_3	Plane_Twin	2	1	1.4	3	1.3	7	1.2
5_1	Truck	4	8	1.6	20	1.2	40	0.8
5_2	Plane_Sngl	3	1	0.75	2	0.6	3	0.51
5_3	Plane_Twin	2	1	1.4	3	1.3	7	1.2
6_1	Tunnel	1	2	8	5	7	12	5
7_1	Plane_UL	8	2	0.8	4	0.72	10	0.56
8_1	Truck	6	6	1.5	12	0.9	24	0.48
8_2	Auto	8	3	0.24	15	0.2	30	0.12
8_3	Plane_Sngl	3	2	0.6	4	0.54	6	0.51
8_4	Plane_Twin	2	1	1.4	2	1.3	3	1.2
8_5	Truck	9	5	2.25	10	1.35	20	0.45
8_6	Auto	12	3	0.36	10	0.3	20	0.18
8_7	Truck	9	3	2.25	6	1.35	10	0.45
8_8	Auto	12	3	0.36	10	0.3	20	0.18

Shown here are the specific data used for the Capacity Function described in the formulation discussion in Chapter 3. Each break point threshold indicates the upper bound to which each asset has a certain monthly per-unit capacity as indicated by the corresponding slope. The bp_3 threshold also signifies the upper limit of a given resource that may be applied to the arc. Using the single-engine plane on arc 1_2 as an example, we see that one plane may make two round trips per month. A graphical depiction of the arc 1_2 capacity function is provided in Figure 20.

Figure 20 is a specific version of Figure 12 (in Chapter III) using the data for FNet arc 1_2.

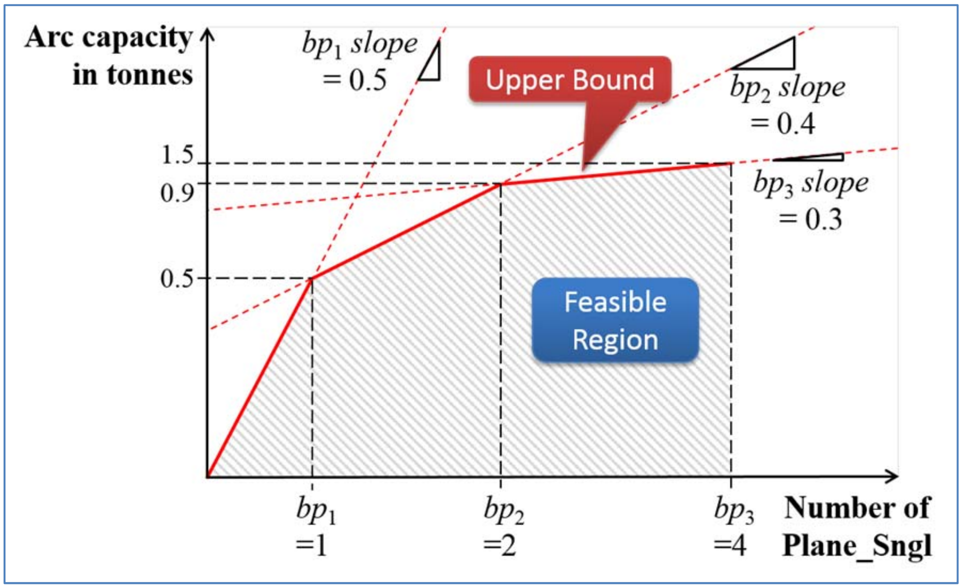

Figure 20. Piecewise-Linear Capacity Function for a Specific Functional Network Arc

This is a specific example of Figure 12 in Chapter III for FNet arc 1_2 that uses the single-engine plane resource. The only values provided in the data are the breakpoint-slope pairs. The capacity of the arc is then derived from the number of planes applied by the SNet DTO nodes. If four airplanes are provided, the arc capacity is 1.5t, whereas if three airplanes are provided, the arc capacity is 1.2t.

Resource cost data specific to each FNet arc are shown in Table 15.

Table 15. Functional Network Resource Cost Data

FNet Arc ID	Mode	Round Trips (R/T) per Month	Cost per Round Trip ($1MM)	Total Monthly Cost per Unit Resource ($1MM)
1_1	Truck	6	0.0002	0.0012
1_2	Plane_Sngl	2	0.041	0.082
2_1	Truck	6	0.0003	0.0018
2_2	Plane_Sngl	2	0.041	0.082
3_1	Plane_Twin	1	0.1035	0.1035
3_2	Plane_Twin	2	0.1029	0.2058
3_3	GFB_Long	2	0.063	0.126
3_4	SPSS	1	1	1
3_5	GFB_Short	3	0.051	0.153
4_1	Truck	4	0.0008	0.0032
4_2	Plane_Sngl	2	0.0508	0.1016
4_3	Plane_Twin	2	0.0512	0.1024
5_1	Truck	4	0.002	0.008
5_2	Plane_Sngl	3	0.051	0.153
5_3	Plane_Twin	2	0.056	0.112
6_1	Tunnel	1	0.5	0.5
7_1	Plane_UL	8	0.0073	0.0584
8_1	Truck	6	0.0053	0.0318
8_2	Auto	8	0.0051	0.0408
8_3	Plane_Sngl	3	0.0505	0.1515
8_4	Plane_Twin	2	0.0508	0.1016
8_5	Truck	9	0.0002	0.0018
8_6	Auto	12	0.0001	0.0012
8_7	Truck	9	0.0002	0.0018
8_8	Auto	12	0.0001	0.0012

Shown here are the specific cost data for each mode particular to a given FNet arc. The total monthly cost is the product of the number of roundtrips an asset can make and the cost per round trip. These costs are the same no matter which DTO applies the given resource to the given arc. The only exceptions are the increased costs due to the behavior parameters discussed in Chapter IV, Section A.

APPENDIX B. COMPLETE RESULTS

Appendix B provides the complete DTOSFNI model results and is structured similarly to Chapter IV, Section B. All tabular results are shown in decreasing order of reduction in profit from the base, un-interdicted case. Profit and the amount of cocaine flow that reaches the U.S. homeland are highly correlated; dividing the Objective Value for a given attack plan by 100 provides a rough estimate of the associated monthly flow of cocaine that reaches the U.S. in metric tons. Typically, the flow reduction percentage is within 0.6% of the profit reduction percentage. In cases where the error is larger (up to 2.5% error), the approximation described above actually underestimates the flow reductions (e.g., the flow reduction percentage is up to 2.5% greater than the profit reduction percentage). The baseline and single attack plan results are shown in Table 16.

Table 16. Complete One-DTO Attack Plan Results

DTO Attacked	Objective Value ($MM)	Reduction from Base ($MM)	Reduction as a Percentage	Difference in DTO-G Resources Applied
Base	5289.65	N/A	N/A	N/A
A	4167.60	1122.05	21.2%	(0.64)
B	4607.64	682.01	12.9%	(0.64)
E	4622.50	667.15	12.6%	9.49
H	5062.57	227.08	4.3%	29.88
F	5190.45	99.20	1.9%	18.72
G	5289.29	0.36	0.0%	(0.64)
C	5289.59	0.06	0.0%	12.02
I	5289.61	0.04	0.0%	20.74
D	5289.62	0.03	0.0%	0.00

Single attack and baseline, non-interdicted results are shown in decreasing order of effectiveness. The Objective Value is the solution returned by the DTOSFNI model. Reduction from Base is the difference of the particular attack plan results from the baseline case, and is also shown as a percentage. The last column shows how a particular attack plan affects overt DTO-G activity compared to baseline (DTO-G uses 0.64 tunnel in the base case). Red parenthetical values represent a decrease, while black value indicate an increase in overt activity.

Complete dual attack plan results are shown in Table 17.

Table 17. Complete Two-DTO Attack Plan Results

DTO Attacked	Objective Value ($MM)	Reduction from Base ($MM)	Reduction as a Percentage	Difference in DTO-G Resources Applied
AB	474.05	4815.60	91.0%	(0.64)
AE	2688.39	2601.26	49.2%	0.36
GH	3332.43	1957.22	37.0%	(0.64)
AF	3409.25	1880.40	35.5%	(0.64)
BE	3484.50	1805.15	34.1%	(0.64)
EF	3864.38	1425.27	26.9%	19.36
AH	4167.57	1122.08	21.2%	9.88
AI	4167.59	1122.06	21.2%	8.65
AC	4167.60	1122.05	21.2%	(0.64)
AD	4167.60	1122.05	21.2%	(0.64)
AG	4167.60	1122.05	21.2%	(0.64)
BF	4281.24	1008.41	19.1%	5.65
BH	4607.30	682.35	12.9%	9.88
BI	4607.62	682.03	12.9%	10.77
BD	4607.63	682.02	12.9%	(0.64)
BC	4607.64	682.01	12.9%	(0.64)
BG	4607.64	682.01	12.9%	(0.64)
EH	4619.62	670.03	12.7%	38.51
EI	4621.41	668.24	12.6%	40.36
EG	4621.75	667.90	12.6%	(0.64)
CE	4622.50	667.15	12.6%	12.94
DE	4622.50	667.15	12.6%	9.49
HI	4792.82	496.83	9.4%	37.43
CH	4803.95	485.70	9.2%	29.88
FH	4855.79	433.86	8.2%	37.43
GI	4951.72	337.93	6.4%	(0.64)
FG	4964.26	325.39	6.2%	(0.64)
DH	5054.23	235.42	4.5%	29.88
CG	5096.43	193.22	3.7%	(0.64)
DF	5100.49	189.16	3.6%	19.49
DG	5158.92	130.73	2.5%	(0.64)
CF	5169.52	120.13	2.3%	36.00
FI	5185.21	104.44	2.0%	40.36
CD	5188.07	101.58	1.9%	17.83
CI	5289.42	0.23	0.0%	39.84
DI	5289.51	0.14	0.0%	39.38

Dual attacks are shown in decreasing order of effectiveness.

A subset of dual attack plans that provide a marginal benefit over a single attack component is shown in Table 18.

Table 18. Marginally Effective Two-DTO Attack Plans

DTOs Attacked	Objective Value ($MM)	Reduction from Base ($MM)	Reduction as Percentage
AB	474.05	4815.60	91.0%
AE	2688.39	2601.26	49.2%
GH	3332.43	1957.22	37.0%
AF	3409.25	1880.40	35.5%
BE	3484.50	1805.15	34.1%
EF	3864.38	1425.27	26.9%
BF	4281.24	1008.41	19.1%
HI	4792.82	496.83	9.4%
CH	4803.95	485.70	9.2%
FH	4855.79	433.86	8.2%
GI	4951.72	337.93	6.4%
FG	4964.26	325.39	6.2%
DH	5054.23	235.42	4.5%
CG	5096.43	193.22	3.7%
DF	5100.49	189.16	3.6%
DG	5158.92	130.73	2.5%
CF	5169.52	120.13	2.3%
FI	5185.21	104.44	2.0%
CD	5188.07	101.58	1.9%

Only dual attacks that provide a marginal benefit over the maximum single attack component are shown here. For example, a dual AE attack yields a reduction of 49.2% which is greater than a single attack on either DTO-A or -E (21.2% and 12.6%, respectively). Conversely, a dual BC attack is omitted from this table since that attack plan yields a 12.9% reduction, which is what a single attack on DTO-B provides.

A subset of dual attack plans that provide no marginal benefit over a single attack component is shown in Table 19.

Table 19. Marginally Ineffective Two-DTO Attack Plans

AC	AH	BD	BI	DE	EG
AD	AI	BG	CE	DI	EI
AG	BC	BH	CI	EH	FI

These attack plans provide either fractional (<0.1%) or no additional benefit over a single attack on one of its components. In most cases, the beneficial single attack is on either DTO-A, -B, or -E. DTO-C, -D, and -I proved unfruitful in the single attack results and provide no added value when combined with A, B, or E. It is noteworthy to see that the EG and the EH attacks have no benefit over a single DTO-E attack, even though each comprise 2/3 of the Mexican cartel leadership triad.

Complete triple attacks are shown in Table 20.

Table 20. Complete Three-DTO Attack Plan Results

DTO Attacked	Objective Value ($MM)	Reduction from Base ($MM)	Reduction as a Percentage	DTO Attacked	Objective Value ($MM)	Reduction from Base ($MM)	Reduction as a Percentage
ABC	474.05	4815.60	91.0%	**ADH**	4167.55	1122.10	21.2%
ABD	474.05	4815.60	91.0%	**ADI**	4167.56	1122.09	21.2%
ABE	474.05	4815.60	91.0%	**ACI**	4167.59	1122.06	21.2%
ABF	474.05	4815.60	91.0%	**ACD**	4167.60	1122.05	21.2%
ABG	474.05	4815.60	91.0%	**ACG**	4167.60	1122.05	21.2%
ABH	474.05	4815.60	91.0%	**ADG**	4167.60	1122.05	21.2%
ABI	474.05	4815.60	91.0%	**HFI**	4205.19	1084.46	20.5%
EFG	1353.45	3936.20	74.4%	**FGI**	4275.10	1014.55	19.2%
AEF	1929.94	3359.71	63.5%	**BFH**	4280.61	1009.04	19.1%
AEH	2688.38	2601.27	49.2%	**BFI**	4281.05	1008.60	19.1%
AEI	2688.38	2601.27	49.2%	**BFG**	4281.19	1008.46	19.1%
AEC	2688.39	2601.26	49.2%	**BCF**	4281.24	1008.41	19.1%
AED	2688.39	2601.26	49.2%	**CFH**	4420.86	868.79	16.4%
AEG	2688.39	2601.26	49.2%	**CEH**	4429.90	859.75	16.3%
BEF	2726.09	2563.56	48.5%	**CEG**	4496.61	793.04	15.0%
GHC	3062.86	2226.79	42.1%	**CFG**	4534.99	754.66	14.3%
GHF	3158.52	2131.13	40.3%	**DEH**	4536.20	753.45	14.2%
EHG	3173.86	2115.79	40.0%	**BDG**	4551.02	738.63	14.0%
GHA	3189.47	2100.18	39.7%	**BHI**	4573.38	716.27	13.5%
GHB	3223.56	2066.09	39.1%	**DEG**	4580.54	709.11	13.4%
GHI	3239.55	2050.10	38.8%	**BCD**	4586.41	703.24	13.3%
GHD	3243.5	2046.15	38.7%	**CHI**	4599.53	690.12	13.0%
AFD	3319.27	1970.38	37.2%	**BCH**	4606.58	683.07	12.9%
AFH	3409.24	1880.41	35.5%	**BGI**	4606.79	682.86	12.9%
AFC	3409.25	1880.40	35.5%	**BDH**	4607.29	682.36	12.9%
AFG	3409.25	1880.40	35.5%	**BDI**	4607.61	682.04	12.9%
AFI	3409.25	1880.40	35.5%	**BCI**	4607.62	682.03	12.9%
BEH	3484.46	1805.19	34.1%	**BCG**	4607.63	682.02	12.9%
BEI	3484.47	1805.18	34.1%	**CEI**	4621.09	668.56	12.6%
BEC	3484.50	1805.15	34.1%	**DEI**	4621.37	668.28	12.6%
BED	3484.50	1805.15	34.1%	**CDE**	4622.49	667.16	12.6%
BEG	3484.50	1805.15	34.1%	**CGI**	4684.75	604.90	11.4%
EFD	3774.43	1515.22	28.6%	**DHI**	4717.74	571.91	10.8%
BFD	3831.21	1458.44	27.6%	**DFH**	4729.27	560.38	10.6%
EFH	3862.48	1427.17	27.0%	**DFG**	4754.48	535.17	10.1%
EFI	3863.08	1426.57	27.0%	**CDH**	4772.44	517.21	9.8%
EFC	3864.38	1425.27	26.9%	**DGI**	4821.96	467.69	8.8%
EHI	3911.00	1378.65	26.1%	**CFI**	4845.83	443.82	8.4%
EGI	4012.06	1277.59	24.2%	**CDG**	4861.18	428.47	8.1%
AHI	4166.50	1123.15	21.2%	**CDF**	4909.22	380.43	7.2%
AGI	4167.20	1122.45	21.2%	**DFI**	4997.96	291.69	5.5%
ACH	4167.45	1122.20	21.2%	**CDI**	5167.65	122.00	2.3%

Applied DTO-G resources are not included in the results.

A subset of triple attacks that provide marginal benefit and perform better than a single attack on DTO-E is shown in Table 21.

Table 21. Marginally Effective Three-DTO Attack Plans

DTOs Attacked	Objective Value ($MM)	Reduction from Base ($MM)	Reduction as Percentage
EFG*	1353.45	3936.20	74.4%
AEF*	1929.94	3359.71	63.5%
BEF*	2726.09	2563.56	48.5%
GHC*	3062.86	2226.79	42.1%
GHF*	3158.52	2131.13	40.3%
EHG	3173.86	2115.79	40.0%
GHA*	3189.47	2100.18	39.7%
GHB*	3223.56	2066.09	39.1%
GHI*	3239.55	2050.10	38.8%
GHD*	3243.50	2046.15	38.7%
AFD*	3319.27	1970.38	37.2%
AFH*	3409.24	1880.41	35.5%
EFD*	3774.43	1515.22	28.6%
BFD*	3831.21	1458.44	27.6%
EHI	3911.00	1378.65	26.1%
EGI	4012.06	1277.59	24.2%
HFI	4205.19	1084.46	20.5%
FGI	4275.10	1014.55	19.2%
CFH	4420.86	868.79	16.4%
CEH	4429.90	859.75	16.3%
CEG	4496.61	793.04	15.0%
CFG	4534.99	754.66	14.3%
DEH	4536.20	753.45	14.2%
BDG	4551.02	738.63	14.0%
BHI	4573.38	716.27	13.5%
DEG	4580.54	709.11	13.4%
BCD	4586.41	703.24	13.3%
CHI	4599.53	690.12	13.0%

Only the 28 triple attacks that provide a marginal benefit over the maximum underlying single attack or dual attack component, and perform better than a single attack on DTO-E, are shown here. An asterisk indicates marginally effective attack plans that build upon the top seven dual attack plans; the two leading letter in each attack indicate the dual attack being augmented. Of note, there are no triple attacks that include AB included in these results.

A subset of triple attacks that perform no better than a single attack on DTO-E is shown in Table 22.

Table 22. Three-DTO Attack Plans That Yield Negligible Results

CGI	CDH	DFG	DGI
CDF	CDI	DFH	DHI
CDG	CFI	DFI	

These 11 triple attack plans provide yield no better profit reductions than does a single E attack plan. Another 45 triple attack plans provide little (<0.1%) or no marginal benefit over the best underlying dual attack plan component.

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